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Institute and Related Activities

The Neutralized Series Conduction Motor on A-C. and D-C. Circuits*

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IT was discovered, in the early eighties, that an ordinary d-c. series conduction motor with a laminated magnetic circuit would operate on alternating current. In those days d-c. series motors usually had few armature and many field ampere-turns and were not neutralized, with the result that, when operated on alternating current, their power factor was very low. Some of the difficulties of the situation were probably first pointed out by G. Kapp, in 1888 or thereabouts. In 1890 Eickemeyer addressed himself to the single-phase series motor and made a commercial machine of it by neutralizing the armature reaction and showing that, contrary to the then prevailing d-c. practise, the armature ampere-turns should be greatly in excess, in fact a multiple of, the motor field producing ampere-turns. He also pointed out that these machines were better suited for operation on low than on high periodicities and that they should be built with small air gaps. Beginning about the year 1893 A. G. Helios of Cologne, Germany, built a large number of neutralized single-phase series motors for general stationary work. Ganz & Co. of Budapest, Hungary, also made many single-phase series motors, beginning about 1889, but do not appear to have employed neutralizing windings. The machines built by these European firms were mostly small, seldom exceeding 20 B. h. p. The reason why the single-phase series motor was first used commercially in Europe, is probably to be found in the fact that in the early 90's the periodicities mostly employed in this country were about twice as high as those in vogue in Europe. The advent of the commutatorless polyphase motor had no doubt much to do with the almost complete abandonment of the single-phase series motor somewhere along the year 1896.

In 1902 the single-phase series motor was applied to railroad work by B. G. Lamme, in this country, and by G. Finzi in Italy. This application proved well justified and revived the interest in this motor. A large number of such motors were built, gave every satisfaction and are still being used. In a number of cases the same machine was operated on direct current within city limits and on alternating currents outside of these. This could readily be done; for a well-designed single-phase series motor is in fact nothing but a series d-c. machine of superlative design with particularly good commutation.

Having demonstrated its ability to satisfy the very exacting requirements of heavy railroad work, engineers would certainly not have hesitated to make use of this well developed machine in any other field if a demand had arisen. This does not seem to have occurred until some five years later, when single-phase fractional horse power motors were called for. In view of past experience, no difficulty was, of course, experienced in building neutralized single-phase series motors for this extremely light duty, and the fact that this machine could be operated with nearly the same characteristics on d-c. circuits of same voltage, also contributed to its popularity in this new field.

Most of the series motors for use, both on a-c. and d-c. circuits, are built without defined polar projections. M. Deri was probably the first to suggest this construction in 1898; M. C. A. Latour and A. P. Zani contributed to this art in 1904 (See U. S. patents 614, 373; 630,492; 787,303; B. P. 514 of 1905). Others have worked in this field more recently. The following remarks will be mainly directed to this type of which there are three main forms.

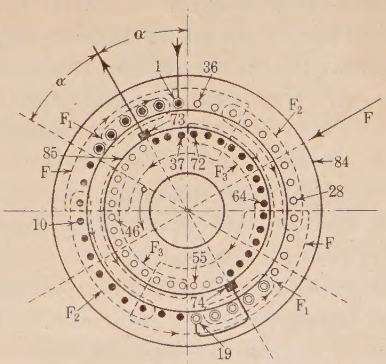

Fig. 1

The two-pole motor illustrated in Fig. 1 comprises a stator 84 and a rotor 85. The stator is provided with 36 equidistant slots, numbered 1 to 36, located near its inner periphery, and diagrammatically represented in the figure by means of small circles, some of which are totally filled in, while others are not. The rotor is provided with 36 slots, numbered 37 to 72, located near its outer periphery, and also diagrammatically represented by means of small circles, some of which are totally filled in. All of the stator and all of the rotor slots carry conductors, the direction of the current in which is shown in the drawing, it being assumed that the conductors in the slots indicated by totally filled in circles carry current directed *down* through the plane of the paper while those in the slots indicated by circles which are not filled in, carry current directed *up*

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through the plane of the paper. The rotor is provided with an ordinary commuted winding connected in practise to a commutator, not shown in the figure, and cooperating with the brushes 73, 74. In the figure these brushes are supposed to rest directly on the commuted winding, with the result that the axis of the magnetization produced by the rotor becomes independent of commutator connections and always coincides with the brush axis. The stator may carry any kind of evenly distributed winding. A conductor entering slot 1 from the front, may, for instance, be returned to the front through slot 36, sent back through slot 2, returned through slot 35, and so on, finally coming back to the front through slot 19. The stator and the rotor windings are connected in series by way of the brushes 73, 74, as shown in the figure; the current entering the stator at slot 1, leaving it at slot 19, entering the rotor at brush 74, and leaving it at brush 73. While the number of slots in stator and rotor is the same in Figs. 1, 5 and 8, this is by no means a necessary condition. Furthermore, each of the slots may carry one or more conductors. The brushes 73, 74 are usually mounted on a common carrier capable of being revolved about the shaft of the motor so as to permit of the rotor axis being displaced with respect to the stator axis. In order to make a neutralized series motor of this machine, it is necessary to so displace the rotor axis with respect to the stator axis as to annul, as nearly as possible, the flux produced by the armature ampere-turns.

It is apparent that three distinct cases may arise:

(a) The effective stator ampere-turns may be in excess of the effective rotor ampere-turns.

(b) The effective rotor ampere-turns may be in excess of the effective stator ampere-turns.

(c) The effective stator ampere-turns may equal the effective rotor ampere-turns.

Ampere-turns rather than turns are spoken of so as to avoid all indefiniteness. Such indefiniteness could, for instance, arise from the fact that a number of turns will produce, with the same line current, more ampere-turns with one style of winding than with another. The term "effective" is used so as to exclude the ampere-turns due to the current in the coils undergoing commutation or such as are rendered ineffective by the use of chord windings and so on.

1. Dealing with the first case, illustrated in Fig. 1, we will assume that the number of conductors per slot is so chosen that there are 116 evenly distributed effective stator ampere-turns to every 100 evenly distributed effective rotor ampere-turns. The question arises, whether the brushes 73, 74 can be so displaced as to produce a fully neutralized series motor.

It is necessary to settle on some initial brush position in order to be able to speak of a brush displacement. Leaving the rotor and stator interconnected in the manner shown, the initial brush position may be taken as that in which the brush axis is displaced by 90 electrical degrees from the axis of the stator magnetization, brush 73 being, for instance, located just below and between the stator slots 9 and 10. This arrangement corresponds to that diagrammatically represented in Fig. 2, and in this case, the distribution of the stator winding is of little interest. In order to secure as much neutralization of the armature ampere-turns as conditions will allow it is, in this case, necessary to move the brushes clockwise *against* the direction of rotation of the machine, which direction is indicated by the curved arrow on the rotor.

If we select as the initial position that in which the stator and rotor axes coincide and the two members produce magnetizations of same direction, in other words, that in which brush 73 is placed just below and between the stator slots 18 and 19, then the arrangement becomes inoperative and in order to convert the machine into a neutralized series motor by means of the smallest movement of the brushes, it is necessary to displace these in a direction opposed to the desired direction of rotation of the rotor.

But the stator and rotor axes can also concide while the two members are producing magnetizations op-

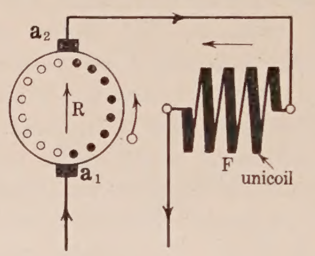

Fig. 2—Single-Phase Series (Conduction) Motor

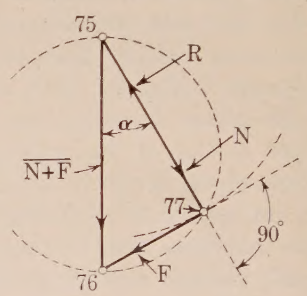

Fig. 3

posed in direction, in which case the brush 73 will be located just below and between the stator slots 1 and 36. This is also an inoperative combination; in order to convert the machine into a neutralized series motor by means of the smallest movement of the brushes, it is necessary to displace these in the direction in which the rotor is to move. In the following it will be assumed that the initial position is that in which the rotor and stator axes coincide while the two members produce oppositely directed magnetizations.

In order to find the angle by which the brushes 73, 74 of Fig. 1 should be displaced in order to secure full neutralization of those rotor ampere-turns which do duty as armature ampere-turns, it is only necessary to describe a circle over the vector 75, 76 of Fig. 3, representing all the stator ampere-turns $\overline{N + F}$ in magnitude and direction, and to find the points of intersection between said circle and an arc described about the point 75 with a radius equal in magnitude to the ampere-turns produced by the rotor. For a counterclockwise displacement of the brush axis, the point of intersection is at 77. The vector 77, 75 then shows the magnitude and direction of the rotor ampere-turns R, and if the

brushes 73 and 74 of Fig. 1 are displaced from their initial position in a counterclockwise direction through an angle α equal to that by which the vector 75, 77 is displaced from $\overline{N+F}$, then the ampere-turns R, produced by the rotor, will be equaled and opposed by the component N of the stator ampere-turns, while another component F thereof, represented as to magnitude and direction by the vector 77, 76 in Fig. 3, will produce the *motor field* of the machine. In the case of Fig. 1 where the stator exceed the rotor ampere-turns, the former are divided into two components, N and F. The first is co-axial with the rotor ampere-turns and opposed to them in direction, while the second is at right angles to the rotor ampere-turns. All the rotor conductors do duty as armature conductors. The conductors contributing to the stator component N are located in the stator slots 7 to 18 and 25 to 36 inclusive, and do duty as *neutralizing conductors*. The conductors responsible for the component F, do duty as *exciting or motor field conductors*, and are located in the stator slots 1 to 6 and 19 to 24 inclusive. Each of these slots is distinguished from the remainder by means of an additional circle. They are located within the angle 2α bisected by the brush axis. The resulting neutralized series motor with stator excitation is diagrammatically represented in Fig. 4.

2. Turning now to the second case and assuming that the number of conductors per slot in the machine shown in Fig. 5, is such that there are 116 evenly distributed effective rotor ampere-turns for every 100 evenly distributed effective stator ampere-turns, and starting from an initial brush position in which the

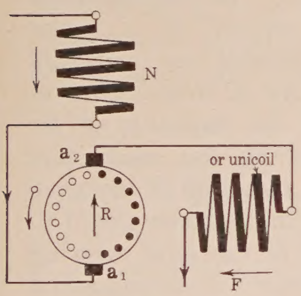

Fig. 4—Neutralized Single-Phase Series (Conduction) Motor

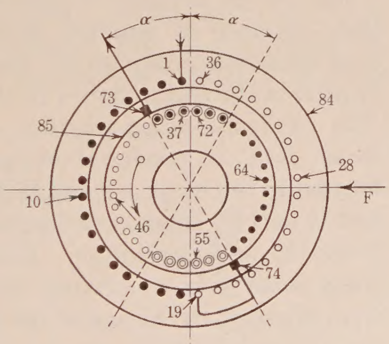

Fig. 5

stator magnetizations are co-axial but opposed in direction, it is possible, by means of Fig. 6, to ascertain the angle through which the brushes should be moved in order to secure complete neutralization of those rotor ampere-turns which do duty as armature ampere-turns. In Fig. 6 the total rotor ampere-turns $R + F$ are represented as to magnitude and direction by the vector 80, 78. In order to find the correct relative position of stator and rotor axes, it is only necessary to describe a circle over this vector and find its points of intersection with an arc described about the point 78 with a radius equal in magnitude to the stator ampere-turns N. For a clockwise displacement of the stator axis corresponding to a counterclockwise displacement of the brush axis, the point of intersection is at 79. The line 78, 79 then represents the magnitude and direction of the stator ampere-turns. In this case it is the rotor ampere-turns which are divided into two components at right angles to each other. The component R is equal in magnitude and opposed in direction to the

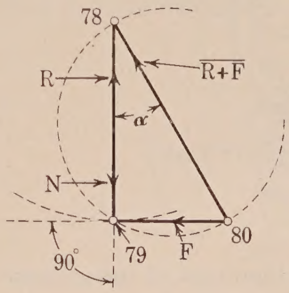

Fig. 6

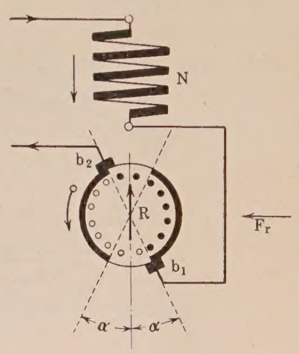

Fig. 7—Neutralized Single-Phase Series (Conduction) Motor with Rotor-Excitation

stator component N. The stator slots carry nothing but *neutralizing conductors*. The component R is produced by conductors located in the rotor slots 40 to 51 and 58 to 69 inclusive. These conductors do duty as *armature conductors*. The other component F produces a magnetization at right angles to the stator magnetization and is due to the rotor conductors located in the slots 70 to 39 and 52 to 57 inclusive. Each of the slots accommodating these *exciting conductors* is distinguished from the remainder by means of an additional circle. These exciting conductors correspond to those located in the stator slots 1 to 6 and 19 to 24 inclusive of Fig. 1. In Fig. 5 the motor field producing conductors are located within the angle 2α, bisected, not by the brush axis as in Fig. 1, but by the stator axis. In this case, the brushes are displaced from their initial position in the same direction and to the same extent as in Fig. 1. The resulting neutralized series motor with rotor excitation is diagrammatically illustrated in Fig. 7.

3. The third case, in which the effective stator and rotor ampere-turns are equal, is illustrated in Fig. 8, it being assumed that for every 116 equally distributed stator ampere-turns there are the same number of equally distributed rotor ampere-turns. Assuming the same initial brush position as in Figs. 1 and 5, the question of how the brushes are to be displaced in order to produce complete neutralization of the rotor ampere-turns doing duty as armature ampere-turns, can be answered with the help of Fig. 9. In this case the vector representing the stator ampere-turns is, of course, equal in magnitude to the vector representing the rotor

ampere-turns. If the stator ampere-turns are to be decomposed into two components at right angles to each other, then the point of intersection of these components must lie on a circle, the center of which coincides with the middle point of the stator vector. The same obviously holds true for the vector representing the rotor ampere-turns. When the two equal stator and rotor ampere-turn vectors are co-axial, but opposed in direction, then the two members will fully

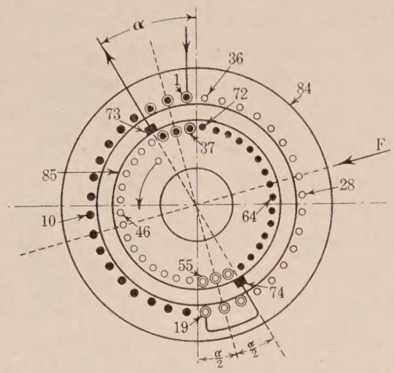

Fig. 8

placed, the one from the other, then part of the ampere-turns on one member will be neutralized by a corresponding part of the ampere-turns on the other member, while the remainder of the ampere-turns on each of the members will contribute to the resultant magnetization. The conclusion is soon reached that, for the case of ampere-turn equality in stator and rotor, a fully neutralized series motor will result *for any angle* through which

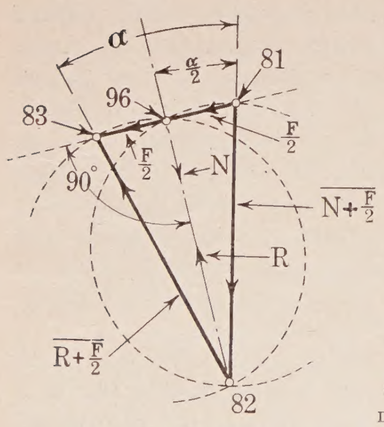

Fig. 9

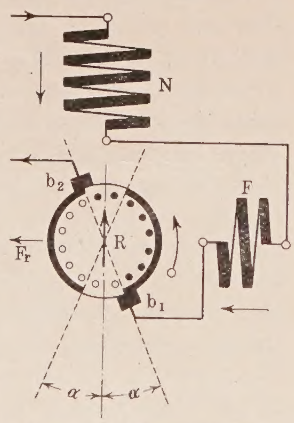

Fig. 10—Neutralized Single-Phase Series (Conduction) Motor with Rotor and Stator Excitation

the brushes are displaced from the initial position, except for a displacement of 180 and 360 degrees. When the brushes are in the initial position, then the stator ampere-turns fully neutralize the rotor ampere-turns and vice versa, and the arrangement is inoperative. The same, of course, holds true for a brush displacement of 360 degrees in either direction. When the brushes are displaced through 180 degrees in either direction, then the magnetizations produced by the two elements neutralize each other. When these vectors are dis-are co-axial and of same direction, and the arrangement is again inoperative. The distribution of the ampere-turns for any other displacement of the brushes, for instance, that indicated in Fig. 8, is ascertained as shown in Fig. 9. The intersection point 96 of the circles described about the middle points of the rotor vector 82, 83 and the stator vector 81, 82, respectively, is also the point of intersection for the two rotor and the two stator components. Thus the rotor ampere-turns for an angular brush displacement α, are to be divided into a component R, represented by the vector 82, 96, and into a component $F/2$, represented by the vector 96, 83. Similarly, the stator ampere-turns, represented by the vector 81, 82, are to be decomposed into one component $F/2$, represented by the vector 81, 96 co-axial with and of same direction as the component $F/2$ of the rotor ampere-turns, and into a component N co-axial with and opposed to the component R of the rotor ampere-turns and represented by the vector 96, 82. The rotor component R is due to the conductors

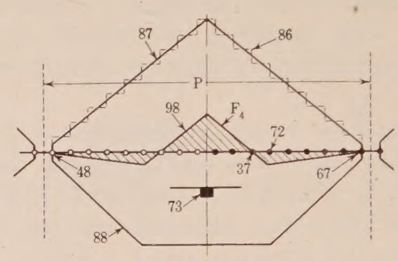

Fig. 11

located in the slots 40 to 54 and 58 to 72 inclusive. These are the *armature conductors*. The magnetization they produce is equaled and opposed by a stator magnetization produced by the *neutralizing conductors* located in the stator slots 4 to 18 and 22 to 36 inclusive. The resultant magnetization of the machine, or *the motor field*, is produced in part by the conductors located in the rotor slots 37 to 39 and 55 to 57 inclusive and in part by conductors located in the stator slots 1 to 3 and 19 to 21 inclusive. Each of the slots carrying these *motor field or exciting conductors* is distinguished from the rest by means of an additional circle. They are all located within the brush displacement angle α, bounded on one side by the stator and on the other by the brush or rotor axis. The resulting neutralized series motor with rotor and stator excitation, is diagrammatically illustrated in Fig. 10.

4. So far nothing but stator and rotor *ampere-turns* have been considered, the brushes being so shifted as to oppose the ampere-turns due to the rotor conductors doing duty as armature conductors, by an equal number of stator ampere-turns. But the real object of neutralization is to produce a machine in which the *magnetization* produced by the armature conductors is equaled and opposed by a stator magnetization. To this end it is not always sufficient to secure an equality

of ampere-turns. It is also necessary that these ampere-turns produce magnetizations of identical space distribution.

Reverting to Fig. 1, the shape of the magnetic field produced by all the rotor ampere-turns R, is correctly outlined by the dotted broken line 86 of Fig. 11. In order to simplify the drafting, this broken line is replaced by the averaging line 87, and this scheme is followed in Figs. 12, 13, 14, 15 and 16, for the same reason. The equal and opposite stator ampere-turns N are due to the conductors located in the slots 7 to 18 and 25 to 36 inclusive, and the magnetization they produce has the shape outlined by the line 88. It is at once seen that the magnetic flux 88 cannot fully neutralize the magnetic flux 87. The difference is the magnetization F_4 shown by the shaded area of Fig. 11, outlined by the broken line 98.

In the case of Fig. 5, the rotor magnetization R produces a trapezoidal magnetization, whereas the opposing stator field N has the shape of a triangle. Here again the neutralization is not complete, the remaining difference or resultant magnetization F_4 being indicated by the shaded area outlined by the line 97 of Fig. 13.

In the case of Fig. 8, the stator magnetization N it not only equal and opposed to the rotor magnetization R, but is of identically the same shape as the latter, as shown in Fig. 15 by the lines 93 and 94.

In Fig. 1 the motor field is due to the conductors located in the stator slots 1 to 6 and 19 to 24 inclusive, and has the shape outlined by line 91 of Fig. 12. In the case of Fig. 5, this motor field has exactly the same shape as in Fig. 1, as shown by the line 92 of Fig. 14, but is due to the rotor conductors located in the slots 70 to 39 and 52 to 57 inclusive. As to Fig. 8, the motor field has the shape indicated in Fig. 16 by the line 95 and is due to the stator conductors located in the slots

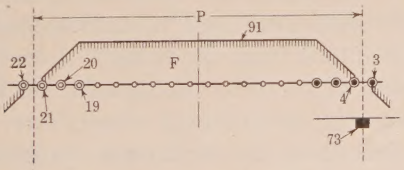

FIG. 12

1 to 3 and 19 to 21 inclusive, and to the rotor conductors located in the slots 37 to 39 and 55 to 57 inclusive.

In Figs. 11 to 16 the extent of the pole pitch is in every case indicated by the letter p, showing that in the case of Figs. 1 and 5 the motor field does not extend over the entire pole pitch, there being a zone of zero magnetization between adjacent poles. In Fig. 12, which represents the motor field conditions in Fig. 1, the iron between the slots 3 and 4 and between the slots 21 and 22 carries no motor field magnetization. Similarly, for the case of Fig. 5, illustrated in Fig. 14, the iron between the slots 37 and 72 and between 54 and 55 carries no magnetization. In the case of Fig. 8 no such zones exist, as clearly shown by Fig. 16. While attention is drawn to this fact, yet it must be remembered that these remarks are only true for the conditions assumed to prevail in Figs. 1, 5 and 8. A different number of slots in the rotor, or stator, or in both, or a different position of the brushes relatively to the commuted winding with which they co-operate will conduce to somewhat different results in this respect.

No matter how the brushes in Figs. 1 and 5 are shifted, it will never be possible to secure perfect neutralization of the armature reaction. There will always remain in the armature axis a resultant magnetization F_4, threading both stator and rotor. Integrating F_4 over a whole pole pitch brings out the fact that this magnetization is really very small as a whole, even though it reaches high values in spots, for the reason that it is not of uniform direction.

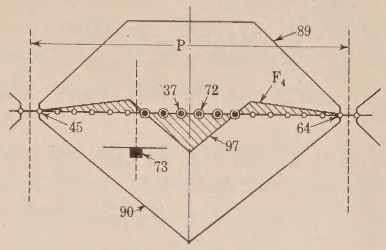

FIG. 13

5. Another question of interest is that of leakage fields, by which is meant any field which links with stator conductors without linking with rotor conductors and vice versa. Referring to Fig. 1, it is seen that there will be a leakage field F_1 surrounding the stator exciting conductors; a leakage field F_2 surrounding the stator neutralizing conductors, and a leakage field F_3 surrounding the rotor armature conductors. These leakage fields are only approximately indicated in Fig. 1 by means of dotted lines surrounding a part of the conductors to which they are due.

Although the leakage fields are not indicated in Fig. 5, yet it will be seen at a glance that the conditions are exactly the same as in Fig. 1, and that the leakage fields F_1, F_2, F_3 will therefore be present, but F_1 is here a rotor and not a stator leakage field.

Fig. 8 differs from Figs. 1 and 5 as regards leakage fields in that the flux F_1 is absent, or at least reduced to very small proportions. Because one-half of the exciting ampere-turns is located on the stator while the other half is located on the rotor, it follows that the formation of a leakage field surrounding the rotor exciting conductors only is opposed by the stator exciting conductors and vice versa, the two sets of conductors tending to magnetize the intervening space in opposite directions. These leakage conditions are just the reverse of those which obtain between the rotor armature conductors and the stator neutralizing conductors. In this instance the intervening space is magnetized by both sets in the same direction.

6. Another point of interest is the commutation. Reference to Fig. 12 will show that in the case of Fig. 1

the conductors undergoing commutation, and the position of which is indicated by the brush 73, are located in or near the neutral zone separating adjacent poles of the motor field F. This location is not detrimental to commutation. These same conductors are, however, so placed with respect to the field F_4 as to be within the maximum density of this flux, as indicated by the brush 73 in Fig. 11. The direction of F_4 at this point is such as to adversely influence the commutation.

In Fig. 5 the brushes are not in the neutral zone of the motor field F, which in this case is located between the slots 37 and 72, but are moved out of it *in* the direction of rotation, thus bringing the conductors undergoing commutation within the full density of the motor field, as shown by brush 73 in Fig. 14. The direction of this motor field is inimical to good commutation. With regard to F_4 the conductors undergoing commutation are in a little better position, as shown by brush 73 in Fig. 13; they are exposed to a part of the flux which influences the commutation adversely, but is of low density.

The conditions prevailing in the case of Fig. 8 are very much the same as those obtaining in Fig. 5; they are indicated by the position of brush 73 in Figs. 15 and

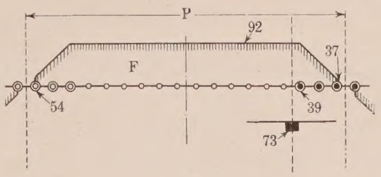

FIG. 14

16. The motor field affects commutation adversely, but F_4 is zero and therefore does not add to the difficulties.

7. The direction of rotation of the motors shown in Figs. 1, 5 and 8, is indicated by a curved arrow in each case. In order to secure identical results for a clockwise rotation of the rotor of any of these machines, it is necessary to displace the brushes from their initial position through the same angle α in a clockwise instead of a counterclockwise direction. Exactly the same result could, of course, be achieved by not moving the brush axis, but displacing the stator axis by α degrees to the one or the other side of the brush axis, moving said axis in a direction opposed to that in which the motor is to revolve. It is only necessary to provide the stator with a suitable winding in order to permit of the use of this equivalent method.

It may be of interest to state that the flux F_4 can be eliminated from Fig. 1 by making the total rotor ampere-turns equal to the stator ampere-turns and using a chord winding on the rotor. The pitch of this chord winding should be such as to neutralize the conductors in slots 37 to 42 and 55 to 60 inclusive. Under these conditions the ratio of effective rotor to stator conductors would be restored to 100: 116, F_4 would disappear, the R and N fields assuming identical shapes, and the conductors undergoing commutation would come within the influence of the full motor field as indicated by brush 73 of Fig. 14, for instance. In the case of Fig. 5, field F_4 can be eliminated by distributing the stator conductors between the slots 4 to 15 and 22 to 33 inclusive while leaving the number of effective stator ampere-turns the same as before.

8. Recapitulating the facts so far ascertained we find, for the case of a series motor with evenly distributed stator and rotor windings:

(a) When the effective stator ampere-turns exceed the effective rotor ampere-turns (Fig. 1).

There is *only one* brush position for which the armature ampere-turns are opposed by an equal number of neutralizing stator ampere-turns, but these two sets of ampere-turns do not produce magnetizations of same space distribution, with the result that a small magnetization, F_4, equal to the difference between the two, is left in the armature axis. In order to eliminate F_4 and secure perfect neutralization, the rotor must be provided with a chord winding. The whole of the motor field F is produced from the stator. A leakage field F_1 surrounds the exciting conductors. A leakage field F_2 surrounds the neutralizing conductors. A leakage field F_3 surrounds the armature conductors. The commutation is adversely affected by the maximum density of the field F_4.

(b) When the effective rotor ampere-turns exceed the effective stator ampere-turns (Fig. 5).

There is *only one* brush position for which the armature ampere-turns are opposed by an equal number of neutralizing stator ampere-turns, but these two sets of ampere-turns do not produce magnetizations of same space distribution, with the result that a small magnetization F_4, equal to the difference between the two, is left in the armature axis. This field can be eliminated and perfect neutralization secured by leaving some of the stator slots unwound. The whole of the motor field F is produced from the rotor. A leakage field F_1 surrounds the motor field conductors. A leakage field F_2 surrounds the neutralizing conductors. A leakage field F_3 surrounds the armature conductors. The commutation is adversely influenced by the maximum density of the motor field and by an intermediate density of F_4.

(c) When the effective stator ampere-turns are equal to the effective rotor ampere-turns (Fig. 8).

Perfect neutralization can be had for *any* brush position in which the machine will operate as a motor. A movement of the brushes merely results in altering the ratio between armature and field ampere-turns. The motor field is produced in part by the rotor and in part by the stator. The leakage field F_1 around the exciting conductors is very much smaller than in the two other cases. A leakage field F_2 surrounds the neutralizing conductors. A leakage field F_3 surrounds the armature conductors. The commutation is adversely influenced by the maximum density of the motor field.

The ratio between armature and field ampere-turns, and therefore the speed torque characteristic of this machine, can be varied by simply displacing the brushes and without in any way interfering with the perfect neutralization of the armature reaction (See U. S. P. 1,304,958). No such result can be secured with any other construction known to the author.

9. This analysis makes it at once possible to form an idea as to the manner in which the motors shown in Figs. 1, 5 and 8 will operate on d-c., as well as on a-c., circuits.

In operating these machines from a direct-current circuit, it will be found that leakage fields have very little influence on the results obtained and that the neutralizing of the armature reaction is important

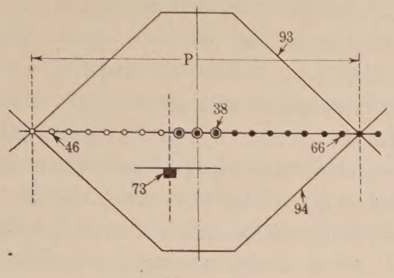

Fig. 15

from the commutating point of view only. Thus, the leakage fields F_2 and F_3 will have no influence whatsoever, while the leakage field F_1 will merely increase the motor field ampere-turns necessary to produce a given motor field. If no neutralizing winding is provided, then the commutation will be very poor, for the coils undergoing commutation will be moving through the area of maximum density of the very strong field produced by the armature ampere-turns R. To secure good commutation, these coils should move through a neutral zone or through a field having a direction opposed to that of the armature reaction. As d-c. machines there is therefore little to choose between the motors shown in Figs. 1, 5 and 8 for the windings selected and the chosen ratios of rotor to stator ampere-turns.

In operating these machines from an a-c. circuit the question of commutation is governed by the considerations already outlined and is complicated by the fact that in Figs. 1 and 8 the motor field F, and in Fig. 5 the motor field as well as the field F_4, will induce disturbing e. m. fs. in the coils undergoing commutation. Furthermore, all leakage fields now have a direct influence on the operation of the machine, for they increase the reactance thereof. The reactance of these motors is due in the main to the motor field F, which, of course, cannot be dispensed with, but also to the leakage fields F_1, F_2, F_3 and the resultant field F_4 in the armature axis. As a-c. machines there is little to choose between them as to commutation, the motors shown in Figs. 1 and 8 perhaps being somewhat better in that respect. But the reactance of the motor shown in Fig. 8 is lower than that of the two others because of the very small value of the leakage field F_1 and the absence of the resultant field F_4 in the armature axis.

In Fig. 17 is shown a time phase diagram of a neutralized single-phase series motor, from which may at once be deduced the fact that the greater the reactance of such a machine, the lower the power factor for a given terminal voltage, periodicity, and speed. This particular diagram illustrates the performance of a four-pole motor, designed in 1902 and yielding 6 B. h. p. at 1000 rev. per min., with a 90 per cent power factor and an 80 per cent efficiency when operated from a 50-cycle supply at 110 volts and 56 amperes. The vector i represents the current, the vector $i\ R$ represents the ohmic drop due to the resistance of the rotor, of the stator, of the brushes, of the brush contact, and of all the leads, plus that due to an imaginary resistance, the loss in which equals the iron loss in the machine (R = .36 ohms). The vector $i\ X$ represents the reactance due to the motor field F, also that due to the leakage fields F_1, F_2, F_3 and to the field F_4 (X = 1.04 ohms). The vector e represents the back e. m. f. generated in the armature by rotation in the motor field, which lags by a few degrees behind the exciting current which in this case is the same as the line current i. Except for this small lag, the phase difference between the terminal voltage E and the line current i, which in this case amounts to 26 degrees at 1000 rev. per min., or at 2/3 of the synchronous speed, is due to the reactance of the machine and varies with the speed. Thus, if the current, and therefore the vector $i\ X$, is kept constant, then the phase difference between E and i will be a maximum when e is zero, that is when the machine is at rest and will decrease with increasing back e. m. f., that is with increasing speed. Under ordinary conditions of operation the terminal voltage of a motor is kept constant

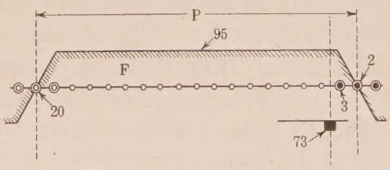

Fig. 16

and the load is varied, with the result that both the current and the speed will change with the load, the current decreasing as the speed increases. The power factor of the machine (which is a measure of the phase difference between the terminal voltage and the line current) will then vary with the speed, somewhat as indicated in Fig. 18. This figure illustrates this variation in the case of the 6 h. p. motor with defined polar projections, the phase diagram of which is shown in Fig. 17.

The work of Eickemeyer first disclosed the manner in which the reactance of a series motor could be reduced to such limits as to allow the machine to operate with a good power factor over most of its speed range. He achieved this object by using very small air gaps, by

neutralizing the armature reaction, that is, by suppressing as nearly as possible the alternating flux in the armature axis, and by providing very few exciting or field, and very many armature, ampere-turns. In his very first machine he selected a ratio of field to armature ampere-turns of 7 to 24. Later, he greatly increased this ratio, reaching, I believe, figures in the neighborhood of 1 : 6. The 6 h. p. motor referred to above, has a field to armature ratio of 6 : 13.2 and shows a fair performance even on 50 cycles. Eickemeyer's teachings were successfully followed in designing neutralized single-phase series motors for traction, and this work added greatly to the detailed knowledge of this type of motor.

The question whether a motor of this kind will or will not have the same operating characteristic on d-c. as on a-c., can be answered with the help of Figs. 17 and 18.

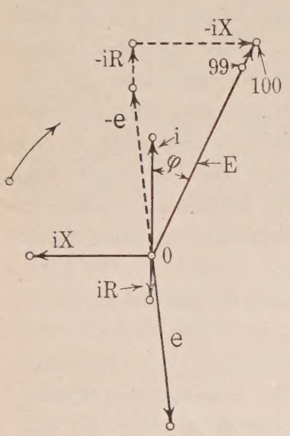

Fig. 17

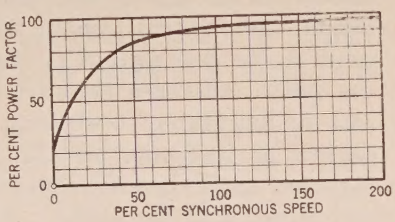

Fig. 18

Referring to Fig. 17, which represents the conditions prevailing at 66 per cent of the synchronous speed, at which, according to Fig. 18, the power factor is 90 per cent, it is seen that, if the motor is transferred from an a-c. to a d-c. supply, the same speed will be reached with the same current when the terminal voltage equals and opposes e and $i\ R$. For d-c. operation $i\ X$ is zero, and there is no phase difference between the current and the motor field, in other words, no phase difference between i and e, which is always in phase with the motor field. The vector 0-100 represents the terminal voltage E required to operate the machine at 1000 revolutions with alternating current. In order to produce the same result when operating the machine from a d-c. circuit, this voltage should be reduced to the value shown by the vector 0-99, which is equal to the arithmetical sum of e and $i\ R$. In order to reproduce some other speed condition when changing from a-c. to d-c., a different change in terminal voltage will have to be made. If it is, for instance, desired to reproduce the conditions existing at 150 per cent of the synchronous speed, then the necessary reduction in the terminal voltage will be even smaller than that indicated in Fig. 17 by the ratio 0 : 100 to 0-99, for at 150 per cent of the synchronous, the power factor of the machine is 97 per cent. On the other hand, if the operating conditions existing at, say 20 per cent of the synchronous speed, were to be reproduced when changing from alternating current to direct current, the terminal voltage would have to be very considerably reduced, because at that speed the power factor of the machine is only 62 per cent. These deductions are, however, not quite exact, because they do not take into consideration the efficiency of the machine. The losses on alternating current are higher than on direct current. This difference increases with increasing periodicity and is mainly due to greater iron losses. The iron losses are greater because losses in the field structure are added to losses in the armature and the latter are increased. The copper losses are greater because of the increased iron losses and of the phase difference between motor field and armature ampere-turns. Unless the turns per commutator segment are kept very low, the flux produced by the coils undergoing commutation will also affect the characteristic of the motor, influencing its speed and efficiency when operated from a direct current and influencing its speed, efficiency, and power factor when operated from an alternating current, source.

These considerations indicate that if the 6 h. p. motor, discussed in connection with Figs. 17 and 18, were to be operated from a d-c. circuit with the same terminal voltage as is applied to it when connected to an a-c. line, then its d-c. speed torque curve would differ from its a-c. speed torque curve. At low speeds, this difference would be very marked because of the low power factor and of the marked difference in efficiency, but with increasing speed the two curves would approach each other, would very nearly coincide over a certain range of speeds above the synchronous, and might even cross. If the d-c. speed torque curve of this machine were compared at constant terminal voltage with an a-c. speed torque curve taken at 100 instead of 50 cycles, the differences just outlined would be very much more marked. Similarly, a comparison of the d-c. speed torque curve with a 25 instead of a 50-cycle speed torque curve taken with the same terminal voltage would show that these differences are less marked. Such results are quite natural in view of the fact that the power factor and efficiency of a given machine approach their d-c. values with decreasing periodicity.

Fig. 17 further indicates that the greater the copper losses as compared with the iron losses and the output of the machine, the greater will be the range of periodicities within which similarity between the a-c. and the d-c. speed torque characteristics can be secured, the lower the speed at which these characteristics will begin to nearly coincide and the greater the speed range over which this similarity will obtain. A change of periodicity displaces the zone of approximate coincidence so that agreement over a wide range of speeds cannot be

expected except for a very reduced range of periodicities.

A change in the reactance of the machine will also displace the zone of approximate coincidence between the a-c. and d-c. speed torque curves of a series motor. One way of changing this reactance is to displace the brushes of a motor.

Applying this method of adjustment to Fig. 1 and displacing the brushes so as to reduce the brush angle α shown in the figure, it will readily be seen, by reference to Fig. 3, that the neutralizing stator ampere-turn component N will immediately exceed the armature ampere-turns R while the exciting stator ampere-turn component F will decrease, with the result that the flux F_4 in the brush axis is increased while the ratio of field to armature ampere-turns is reduced because of the reduced number of exciting ampere-turns. This ratio reduction is not accompanied by a proportional reduction of the reactance of the machine, because of the increased flux F_4. If the brushes are so moved as to increase the angle α of Fig. 1, then F will increase and R will exceed N, with the result that F_4 will grow and owe its direction to R while the ratio of field to armature ampere-turns will increase because of the increased number of exciting ampere-turns F. The reactance of the machine will, however, show a more than proportional rise because of the increased flux F_4.

Considering Figs. 5 and 6, a decrease of the brush angle α will reduce F and cause R to exceed N, with the result that F_4 will grow, owing its direction to R, while the ratio of field to armature ampere-turns will decrease because of the reduction of the former and the increase of the latter. The flux F_4, when of same direction as R, not only increases the reactance of the machine, but also produces a negative torque in co-operation with the rotor exciting ampere-turns. The reduction of the ratio of field to armature ampere-turns is not followed by a proportional decrease of the reactance of the machine because of the increase of F_4. If the brushes are moved so as to increase the angle α of Fig. 5, F will increase and N will exceed R, with the result that F_4 will grow, owing its direction to N, while the ratio of field to armature ampere-turns will increase because of the increase of the former and the decrease of the latter. The flux F_4, when of same direction as N, not only increases the reactance of the machine, but also produces a positive torque in co-operation with the rotor exciting ampere-turns and should, under the circumstances, be looked upon as part of the field flux. The whole of F_4 is not linked with the exciting ampere-turns on the rotor so that part of F_4 merely increases the reactance of the motor. As a result, the reactance of the machine increases a little faster than in proportion to the increase of the ratio of all the field to all the armature ampere-turns.

In the case of Fig. 8, the minimum reactance of the machine occurs when the angle α is zero and the combination is inoperative. As the brushes are displaced, the ratio of field to armature ampere-turns increases and brings about a corresponding increase of the reactance of the machine. Except for this variation in the ratio of field to armature ampere-turns, the machine operates as a fully neutralized series motor for any value of α between 0 and 180 degrees and the flux F_4 is always zero.

A movement of the brushes in either of the figures 1, 5 or 8, is therefore followed by a change in the ratio of field to armature ampere-turns and a change in the total reactance of the motor. In Fig. 8 this change in the reactance is directly proportional to the change in the said ratio. In Figs. 1 and 5 this proportionality does not exist, the reactance changing more rapidly than the ratio of field to armature ampere-turns.

It is not possible to build a series motor which, for same terminal voltage, will show the same speed torque curve with direct current and alternating current of any periodicity, but motors can be built, the speed torque curves of which, will practically coincide within certain speed and periodicity limits. The lower the reactance or the larger the ratio of ohmic resistance to reactance the wider said speed or periodicity limits. It follows that the more inefficient the series conduction machine the wider the periodicity and speed limits within which its performance on an a-c. circuit will coincide with its performance on a d-c. line of same voltage. Machines which show this characteristic to at least some extent have been referred to as "universal motors." Very small a-c. series conduction motors which are at all well designed from the Eickemeyer point of view are inherently "universal" and the only problem in this case is to extend the periodicity and speed limits within which the "universal" feature is maintained without too great a sacrifice in efficiency. On the other hand it is very difficult to produce a "universal motor" in other than fractional horse power sizes as the speed and periodicity limits for which the a-c. and d-c. speed torque curves can be made to coincide narrow down very rapidly with increasing size.

Motors for "universal" service can be built with, or without, pronounced polar projections and in designing them, it is only necessary to follow Eickemeyer's teachings. The type shown in Fig. 8 is particularly convenient for the reason that inaccuracies in predetermination can be corrected after completion of the machine by simply displacing the brushes. A completed machine of this type is also the only one which permits of a variation in the ratio of field to armature ampere-turns while maintaining perfect neutralization. This variation is brought about by displacing the brushes, and influences the speed torque curve of the motor.

Some Development in Insulating Materials and Processes in Great Britain with Special Reference to Thermal Consideration*

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This paper is intended to show the lines along which the manufacturers of electrical apparatus in Great Britain are dealing with their insulation problems.

Particulars are given of the facilities that have been established for insulation research, and the more important developments in insulating materials and processes employed in the various classes of electrical apparatus are discussed with special reference to thermal characteristics and consideration.

The opinions of British electrical engineers upon certain aspects of temperature rating of machinery as affected by insulation are considered.

Survey of Research Facilities

IN 1903 an investigation of the thermal properties of various insulating materials was made on behalf of the British Engineering Standards Committee (now the B. E. S. A.) by the National Physical Laboratory in conjunction with a few of the leading electrical manufacturers. Aside from this, prior to 1914, electrical manufacturers in Great Britain pursued independently investigations in insulating problems, and except for occasional papers presented before technical institutions and contributions to the technical press, rarely made an interchange of experience of mutual interest and importance.

In 1914 the Institution of Electrical Engineers established through its research committee a number of panels for the investigation of certain groups of insulating materials. Similarly the British Electrical and Allied Manufacturers Association appointed a research committee, which has directed considerable attention to a number of insulating problems that were marked as needing immediate inquiry in a census taken among the members of the Association.

The establishment by the Government of a Consultative Committee led in 1916 to the formation of the Department of Scientific and Industrial Research. This department has organized and assisted in the financial support of research associations in various industries in cooperation with manufacturing firms.

Later the Institution joined forces with the Manufacturers Association and established the Electrical Research Committee which obtained grants from the Department of Scientific and Industrial Research and in due course became incorporated in the British Electrical and Allied Industries Research Association (Electrical Research Association).

During this period great difficulty was experienced, due to war conditions, in obtaining adequate supplies of insulating materials, and the Electrical Research Association focussed its attention largely on this problem.

The work of the Association is carried out under the direction of a council operating through sectional and subcommittees. The attention paid to insulating problems can best be judged from the fact that seven out of eleven sectional committees and twenty-three out of a total of thirty-four subcommittees deal with groups of investigations relating to insulation. These groups comprise:—

Fibrous Insulating Materials, including:
- Fabrics untreated and treated.
- Papers untreated and treated.
- Fibres, boards and tubes.
- Varnishes and cements.
- Enamelled wire.
- Rules for conducting electric strength tests.

Composite Insulating Materials, including:
- General research.
- Tooling of composite insulating materials.

Porcelain, including:
- Electrical and mechanical tests.

Mica, including:
- Mica and micanite for commutators.
- Mica for condensers.
- Mechanical properties of mica, etc.
- Micanite.

Insulating Oils, including:
- Chemical, physical and electrical tests and specifications.

Synthetic Resins, including:
- Supplies of constituent raw materials for manufacture of synthetic resins.
- Synthetic varnish-paper boards, tubes, etc.
- Moulded insulation employing synthetic resin.

Dielectrics (in general), including:
- Dielectric losses.
- Thermal resistivity.
- Effect of heat on insulation.

MATERIALS

Most researches, whether carried out cooperatively through the Electrical Research Association or by individual makers and users of insulation, have been directed principally to extending knowledge of the behavior of insulation under varying physical conditions, improving quality, developing more scientific insulating

Presented at the Niagara Falls A.I.E.E. Convention, June, 1922.

processes, defining the requirements of insulation users, and standardizing the methods of testing materials for the benefit of maker and user alike. A most important development has been the increasing tendency in recent years for makers and users of insulation to cooperate either individually or through the medium of the Electrical Research Association. For the most part insulating materials had in the past been supplied by firms having little knowledge of electrical uses or requirements. Conversely, the user, except a few large firms controlling their own sources of supply, knew very little of the problems that confronted the manufacturer of insulation, especially in such materials as fabrics, varnishes and fibrous sheets. For the purpose of this paper the principal developments that have taken place in processes and materials in Great Britain are grouped according to whether they are employed in connection with:

a. Industrial machines.
b. Turbo alternators and other large machines.
c. Transformers.

Industrial Machines

For machines other than traction, crane and mill motors, Class A materials are employed, *i. e.* organic insulation of cotton, silk and paper, either impregnated or untreated. In addition, however, mica wrappings or linings of similar material are employed to a very considerable extent on the slot portions of windings.

Apart from an improved knowledge of their characteristics and their supply in greater uniformity, no very great advance in quality has been made or can be looked for in Class A materials. Certain improvements that are worthy of some note, however, are briefly as follows:

Pressboard

This name is now given to that fibrous insulating material otherwise known as fullerboard, presspahn, etc. which before the war was made only to a very limited extent in England, the supplies being obtained from America or the Continent.

While materials similar to those originally imported are now manufactured in England to meet the requirements of certain markets, newer types of pressboard have been developed along two distinct lines, having the following characteristics:

1. A soft, porous sheet material made from selected and carefully proportioned mixture of fibres and subjected to a manufacturing process which renders the product as absorbent as possible.

This material is principally used for transformers, but is also applicable to machine insulation. Its great absorbent property is secured at the expense of a comparatively low density and correspondingly decreased electric strength.

2. A dense non-absorbent sheet material, during the manufacture of which the fibers are subjected to a process which reduces them to a semi-colloidal state resulting in a product which is very hard and dense, possessing exceptionally high electric strength and capable of withstanding prolonged immersion in hot oil without loss of mechanical properties.

For most uses up to the present, this material has not been required to withstand temperatures over 100 deg. cent., and for convenience in manufacture it has been prepared from a mixture of fibers containing a large percentage of jute. Owing to its ligno-cellulose character however, jute has the characteristic property of becoming somewhat brittle at temperatures higher than about 100 deg. cent., and therefore, if required to meet more severe temperature conditions than this it will probably be necessary at some manufacturing inconvenience to employ a cotton base to secure improved aging properties.

The following table indicates the principal characteristics of these two types of materials together with those of pressboard of ordinary quality, the test for comparative purposes having been made on 1/32-in. thickness of sheet:

Quality	Density	Break-down voltage per mil in air after one minute's application	Per cent of water absorption after 24 hours	Tensile str. in tons/sq. in.		Minimum radius bend without fraction after 24 hours in hot oil at 100 deg. cent.
				With Grain	Across Grain	
Soft absorbent . .	1.10	250	110	3.80	3.50	Folds flat.
Dense non-absorbent......	1.43	518	44	5.2	3.80	3/8 in.
Ordinary grade. . .	1.25	300	110	4.60	3.60	1/8 in.

Varnish Cloth

Considerable progress has been made in the manufacture of varnished cloth and in investigating the behavior of this material under working conditions, particularly the well-known phenomenon of the very excessive reduction of the electric strength with increase in temperature which is more marked in varnished cloth than in other Class A materials.

In manufacture, particular attention has been paid to the specially important point of dressing. A controversy still exists on this point, but many large manufacturers claim that a dressing is essential to prevent varnish coming into close contact with the cotton fibers, as it is considered that such contact deteriorates the cloth in that:

1. The impregnated cloth swells and appreciably lowers the electric strength per unit thickness.

2. The varnish within the capillaries of the fiber does not completely oxidize, at any rate for a very long period, and thus also lowers the electric strength of the material.

3. The above-mentioned slow oxidation of the varnish in close contact with the fiber sets free organic acids which attack the fiber and produce serious weakening or so-called "tendering."

Another important consideration is the suitability of the varnishes used. As to this there are two principal considerations, viz., the resin content and the contents of driers.

If the resin content is too high, the cloth lacks flexibility; if too low, the varnish film lacks sufficient strength to withstand tension without serious diminution of electric strength.

As regards the contents of driers this is a matter of supreme importance. For a varnish film to possess a high dielectric strength the varnish must be oxidized as completely as possible. Too low a content of driers causes poor dielectric strength. There is, however, an upper limit of drier content, and if this is overstepped in the slightest degree bad "tendering" of the fabric results. This "tendering" frequently does not reveal itself until several months after manufacture, and it can take place in a batched and wax protected roll in the absence of air. It is thought that in the presence of excess driers, unstable oxides are formed in the varnish film, and that these gradually decompose with the liberation of free oxygen which causes the "tendering." In all cases where "tendering" results the dielectric strength of the varnished cloth is found to be exceptionally good. No knowledge has yet been found as to the effect of such unstable oxides on the varnish film under actual working conditions, but it is quite possible that in a temperature of 100 deg. cent. their decomposition would be accelerated, and that the film might be further oxidized, either with the formation of an acid sticky mass, or possibly of a friable power. In any case there would be considerable mechanical weakening of the cloth which, coupled with the effects of vibration, might bring about a breakdown.

Synthetic Varnish Paper Boards and Tubes

Materials of this description have of late been the subject of considerable controversy, and the general tendency is to curtail their use until their properties, particularly as regards absorption of moisture and low surface resistance, are more thoroughly understood. A great deal of investigation in this direction is in progress and the limitations of the materials are better understood.

The uneasiness felt in the use of these materials in Great Britain has been intensified by the fact that during the war many different makes were supplied by manufacturers insufficiently equipped in experience and plant to produce commodities requiring such a high degree of technical skill.

Moisture Proof Treatment of Windings

Much consideration has been given to the most satisfactory method of treating windings and two general processes are in favor, viz: vacuum impregnation and dipping, or surface treatment.

For vacuum impregnation on stationary windings bituminous compounds are generally employed, and for rotating windings a varnish which oxidizes only to a limited extent and contains a large percentage of volatile solvent which consequently hardens reasonably well even although it penetrates into interstices not freely exposed to the air. Under such conditions the difficulties of completely oxidizing linseed oil base varnishes are fully appreciated.

In none of the materials employed in these processes has there been any marked improvement in recent years.

While it is generally felt that Class A materials have nearly reached their physical limits of durability under the temperatures and conditions met with in practise, there is still much knowledge to be obtained which will correlate the results obtained in the laboratory with those of practical experience in service.

Turbo-Alternators and Other Large Machines

The tendency has been to employ as far as existing processes render practicable materials of Class B. Some manufacturers do this to a limited extent in the case of stator windings where the materials employed usually consist of combinations of mica with paper or cambric. The volume of mica ordinarily contained in a commercial grade of these materials may be as low as 25 per cent, and as will be seen later this proportion does not compare favorably with that of the insulation practicable on turbo-rotors.

Some other manufacturers insulate the stator windings throughout with mica applied in the form of mica paper tape. With this combination the proportion of mica is much lighter, the thin paper serving only as a support during the application of the mica. Mica silk is also used to a considerable extent and enables the application of a higher percentage of mica to be made.

In the processes of insulation, especially those applied to the slot portions of the windings, every effort is made to compress the insulation to as dense a condition as possible and to eliminate as far as is practicable volatile matter which, apart from a tendency to cause insulation to swell when heated, is liable to condense in the coolest parts of the windings with very deleterious effects to the insulation and risk due to its inflammability.

No effective fire-proof treatment of stator insulation has yet been found, although many investigations are proceeding to this end.

Turbo-rotor windings can be insulated almost entirely with hard-pressed micanite containing not less than 90 per cent by volume of mica. The small quantity of grade A insulation that has to be employed during the assembling of these windings can be disregarded. Further, in supporting the end of the windings an almost non-flammable insulation, such as that prepared from asbestos and synthetic resin, can be used, thus rendering the whole of the insulation of the rotor extremely heat-resisting.

Probably the most marked improvements in the insulation of this group of electrical machinery is the

closer technical control and supervision that is now exercised of insulation processes in the shops and the more rigid selection of the insulation materials employed.

Transformers

Materials of Class A are to a very large extent used. In oil-cooled transformers the solid insulation usually consists of pressboard or varnish-paper board (micarta). In the core type construction the latter material has hitherto been largely used. There is, however, a tendency now to employ pressboard of the very dense quality already described. This material is found to be very strong both electrically and mechanically at the highest temperatures met with in practise. On the other hand shellac varnish-paper in either tube or board form, as ordinarily supplied, softens at temperatures between 75 deg. and 90 deg. cent., and its electric strength at these temperatures is very low. Dense pressboard does not soften and possesses extremely good electrical characteristics. Tests on a cylinder of this material after exposing to a temperature of 80 deg. cent. for twenty hours and, then to oil at a temperature of 90 deg. cent. for two hours, yielded the following breakdown figures:

Instantaneous breakdown	550 volts per mil.
Breakdown after 1 minute	445 volts per mil.
Breakdown after 5 minutes	400 volts per mil.

These results give a time voltage curve at this temperature of a very favorable character.

A very considerable amount of research has been carried out in connection with improvement in the quality of oil used with transformers. The disastrous effects of sludging noted some twelve or fourteen years ago by large transformer users, led to the discovery of the non-sludging character (when properly refined) of the bituminous base white Russian oils. There was a marked tendency among British users before the war to employ this expensive oil, and when the sources of supply were cut off attention was paid to the refinement of paraffin base oils from other sources which up to that time had not shown such excellent properties. A long series of investigations led to the establishment of methods of testing which are now generally accepted in Great Britain and which are about to be embodied in a specification by the British Engineering Standards Association.

The correlation between laboratory tests on highly refined non-sludging oils and their behavior in practise is not as yet very complete. It is possible that their use affords an unnecessary margin of safety in the case in certain types of transformers, and that somewhat cheaper oils would be satisfactory in transformers where there is a minimum amount of bare copper exposed to the catalytic action, and where there is a minimum amount of oil surface exposed to the air.

A considerable amount of research is being carried out in connection with the temperature characteristics of cable insulation both at the National Physical Laboratory and at the works of various cable companies. The complete results of these investigations are not yet available.

Some Rating Considerations

Laboratory Tests and Service Experience

While it is indisputable that the rating of electrical machinery must be based upon the temperature which insulation will withstand, it is becoming appreciated that life tests of insulating materials made under laboratory conditions are of little value as compared with practical experience with the operation of machines under known service conditions and for long periods, and that it is only upon the results of such experience that conclusions as to the durability of insulation can satisfactorily be drawn.

Laboratory tests are of the utmost value in enabling comparisons to be made of the relative properties of different materials and also in the development of new materials and processes. In the past, however, there has been a tendency to attach too great importance to laboratory investigations directed to the determination of the temperatures at which mechanical deterioration occurs and on which temperature ratings should be based. Such investigations have not always taken into account the fact that the surfaces of insulated windings exposed to oxidation are relatively very small as compared with the exposed surfaces of test specimens; and that the rate of deterioration of insulation in the case of windings in service, where there may be a considerable temperature difference between the surface and the cooling air, is likely to differ greatly from that occurring in a laboratory aging oven where no such temperature difference exists. Then again in almost all types of windings the insulation is so completely supported mechanically that any hardening, stiffening or embrittling of its layers may proceed without any attendant risk of failure to a point far beyond that which would appear alarmingly unsafe if such support did not exist.

The increasing tendency for power plant engineers to maintain careful records of temperature performances of their large generator and transformer units will eventually afford data of the utmost value and serve to confirm or amend present ideas as to correct temperature ratings.

Temperature Considerations

It has for long been recognized, especially in connection with large machine windings, that internal temperatures existed considerably higher than the values which have been adopted as standard limits for many years in connection with the older methods of measurement. The temperature limits now proposed for Class B materials under the new methods of measurement, while apparently higher than the figures formerly recognized, do not actually imply higher internal temperatures than have existed in the past, or than the results of experience indicate as safe.

In those cases where conditions permit the use of materials which withstand high temperatures, all the features of design should be viewed in proper perspective and full advantage taken of high temperature limits if by so doing better all round performance results.

In connection with the tendency on the part of British manufacturers to employ in transformers highly refined non-sludging oils, coupled with the use of dense fibrous materials which will withstand high temperatures without deformation or serious loss of insulating value, it is felt by some that the employment of oil conservators safely permits higher temperature limits both in oil and windings than are permissible without the use of these devices.

Ratings Based Upon Temperature Rise

In the case of industrial machines there is a strongly growing opinion among British engineers that in the rating of electrical machinery the decision of the I. E. C. to establish a basis for comparing tenders by different countries according to total temperature was a mistaken policy, and that temperature rise affords a much more satisfactory means of securing this object.

As already noted in connection with Class B materials the combinations of insulation used particularly on turbo-alternators and other large machines differ considerably in the proportions of organic and inorganic materials that they contain, and consequently also in their heat-resisting properties. It is felt that the present classification is unsatisfactory and should be revised, some differentiation being made in the limits set according to the quality and the position in which any particular type of material is used. For instance the insulation that is possible for rotor windings throughout may be relatively of superior heat-resisting quality to that which is sometimes used on the slot portions of stator windings, which again is, in general, superior in this respect to the insulation on stator end windings.

Torque Components Due to Space Harmonics in Induction Motors

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The graphical method or circle diagram is undoubtedly the one most frequently employed in deriving speed-torque curves of induction motors from the design constants of the motor or from running and locked tests readings. In numerous papers and text books on induction motors are described quite a variety of circle diagrams, which have been developed for this purpose, each introducing more or less refined methods into the process. Steinmetz' symbolic method lends itself readily to an analysis of the induction motor phenomena and formulas have been derived by him by means of which the complete performance can be calculated.

However, all these methods are based on sinusoidal impressed voltage and sinusoidal distribution of the rotating field, while it is well known to every designer of induction motors that the actual speed torque curve of a motor may deviate considerably from the curve obtained when calculated by the above methods, due to higher harmonics in voltage wave or field distribution. The harmonics in the impressed voltage wave and field distribution are referred to as time harmonics and space harmonics respectively.

The nth time harmonic, having the same number of poles as the fundamental, but n times the frequency, has a synchronous speed equal to n times that of the fundamental. Within the range of motor speed the torque components produced by time harmonics are, therefore, practically negligible, especially their combined effect, since some rotate forward and some backward, and under no circumstances do they produce sharp indentations in the speed-torque curve anywhere from standstill to synchronism.

Time harmonics are consequently never directly responsible for the tendency which a motor occasionally shows to stick at some speed below synchronism, a phenomenon known as "sub-synchronous speed," although they may assist in a slight degree to bring about this condition in so far as they cause a diminution in the torque of the fundamental wave.

The nth space harmonic, on the other hand, having the same frequency as the fundamental, but n times the number of poles, has a synchronous speed of $1/n$ that of the fundamental. Since the maximum motor torque produced by this harmonic is usually from 10 to 30 per cent below and the maximum generator torque about the same percentage above its own synchronous speed, it follows that the torque developed by it in this range will produce sharp indentations in the fundamental torque curve. If at any time during the acceleration these depressions should cause the motor torque to be reduced below the resisting torque, the motor cannot, of course, speed up past this point, and we then have a case of sub-synchronous speed.

It is obviously desirable to minimize the effect to produce sub-synchronous speeds in so far as it can be

done without otherwise impairing the performance of the motor, and it therefore becomes of importance for the designer to be able to predetermine this effect. Because of the fact that the space harmonics are much more effective in producing sub-synchronous speeds than the time harmonics, and they are, moreover, the only ones which the motor designer is in position to modify, the time harmonics being produced by external causes, this discussion is limited to space harmonics.

It has been shown in Karapetoff's "Magnetic Circuit" (page 125) that the rectangular magnetomotive force of a single coil can be represented by a series of sinusoidal m. m. fs., as follows:

$$M\,(\sin x + 1/3 \sin 3\,x + 1/5 \sin 5\,x + 1/7 \sin 7\,x + \ldots)$$

Where M is the amplitude of the fundamental wave. By resolution of the single-phase m. m. f. into two components revolving in opposite directions it is also shown that the currents in the windings of a polyphase motor produce a magnetomotive force of constant intensity and rotating with uniform velocity.

The following simple analytical method is perhaps more readily applied to the determination of the direction of rotation of the m. m. fs. set up by the higher harmonics.

If the windings of a three-phase induction motor, having one coil per pole per phase and n turns per coil, be excited by currents from a three-phase circuit, the instantaneous values of the magnetomotive forces of the three phases are

$$n\ I_m \cos \omega\, t$$
$$n\ I_m \cos (\omega\, t + 120)$$
$$n\, I_m \cos (\omega\, t + 240)$$

Where I_m is the maximum value of the current in each phase and $\omega = 2\,\pi\, f$, f being the frequency. The magnetomotive forces of phases 2 and 3 can be resolved into components parallel with and perpendicular to the m. m. f. of phase 1, as follows:

$$n\, I_m \cos (\omega\, t + 120)\ (\cos 120 + j \sin 120)$$
$$n\, I_m \cos (\omega\, t + 240)\ (\cos 240 + j \sin 240)$$

multiplying and simplifying these expressions, reduce to

$$n\, I_m\, (0.25 \cos\ \omega\, t - j\, 0.75 \sin\ \omega\, t)$$
$$n\, I_m\, (0.25 \cos\ \omega\, t - j\, 0.75 \sin\ \omega\, t)$$

adding these together with the magnetomotive force of the first phase gives the resultant m. m. f. of all three phases.

$$\frac{3\, n\, I_m}{2}\ (\cos\ \omega\, t - j \sin\ \omega\, t)$$

which is of constant intensity $\frac{3\, n\, I_m}{2}$ and rotating with uniform velocity of $2\,\pi\, f$ radians per second in clockwise direction. Inspection of this expression shows that if each single-phase m. m. f. had been resolved into two components revolving in opposite directions of amplitudes $\frac{n\, I_m}{2}$, the three components revolving in clockwise direction coincide and are added together, while the components revolving in counter-clockwise direction neutralize each other and their sum is equal to zero.

If the phase relation between the currents in the three phases had been

$$I \cos\ \omega\, t$$
$$I \cos\ (\omega\, t - 120)$$
$$I \cos\ (\omega\, t - 240)$$

the resultant m. m. f. would have been found to revolve in opposite direction.

When the above analysis is applied to determine the direction in which the m. m. fs. of the higher harmonics travel with respect to the fundamental it is not necessary to consider the amplitude, and for simplicity it is omitted. It is evident that in the nth harmonic the angular displacement between phases, measured in electrical degrees, is n times that of the fundamental, and the m. m. f. components of the nth harmonic are

$$\cos\ \omega\, t$$
$$\cos\ (\omega\, t + 120) \left(\cos \frac{2\, n\, \pi}{3} + j \sin \frac{2\, n\, \pi}{3}\right)$$
$$\cos\ (\omega\, t + 240) \left(\cos \frac{4\, n\, \pi}{3} + j \sin \frac{4\, n\, \pi}{3}\right)$$

Making $n = 3$, the resultant m. m. f. is zero
Making $n = 5$, the resultant m. m. f. is

$1.5\ (\cos\ \omega\, t + j \sin\ \omega\, t)$, that is backward rotation.
Making $n = 7$, the resultant m. m. f. is

$1.5\ (\cos\ \omega\, t - j \sin\ \omega\, t)$, that is forward rotation.
For $n = 9$ the m. m. f. again vanishes, etc.

Similarly in the two phase system the currents are

$$I_m \cos\ \omega\, t$$
$$I_m \cos\ (\omega\, t + 90)$$

and the m. m. f. components of the second phase parallel with and perpendicular to the first phase are

$$n\, I_m \cos\ (\omega\, t + 90)\ (\cos 90 + j \sin 90) - j\, n\, I_m \sin\ \omega\, t$$

and adding the m. m. f. of the first phase, the resultant is

$n\, I_m\, (\cos\ \omega\, t - j \sin\ \omega\, t)$, or clockwise rotation. Again, the m. m. f. components of the nth harmonic, omitting the amplitude, are

$$\cos\ \omega\, t$$
$$\cos\ (\omega\, t + 90) \left(\cos \frac{n\, \pi}{2} + j \sin \frac{n\, \pi}{2}\right)$$

when $n = 3$ the resultant m. m. f. is

$\cos \omega t + j \sin \omega t$, that is backward rotation.

when $n = 5$ the resultant m. m. f. is

$\cos \omega t - j \sin \omega t$, that is forward rotation, etc.

To sum up the direction of rotation the m. m. fs of the higher harmonics are

Three-phase

7th, 13th, etc., forward rotation
5th, 11th, etc., backward rotation
3rd, 9th, etc., are absent.

Two-phase

5th, 9th, 13th, etc., forward rotation
3rd, 7th, 11th, etc., backward rotation.

In the work referred to it has further been shown that when S coils of one phase are distributed in S slots along the periphery of a core, the slot pitch or displacement angle being α electrical degrees, the amplitude of the resultant m. m. f. of the S coils is the sum of the amplitudes multiplied by the factor.

$$\frac{\sin S\,\alpha/2}{S \sin \alpha/2}$$

Likewise if the winding pitch is different from unity the amplitude of the resultant m. m. f. is further reduced by the factor $\cos \gamma/2$ where $\gamma = \alpha$ times the number of slots pitch deficiency.

Since the pole pitch of the nth harmonic is $1/n$ that of the fundamental, it follows that the α in the nth harmonic becomes $n\,\alpha$ electrical degrees and the above factors will then be changed to

$$\frac{\sin S \dfrac{n\,\alpha}{2}}{S \sin \dfrac{n\,\alpha}{2}} \text{ and } \cos \frac{n\,\gamma}{2}$$

Moreover, since the coefficient of the nth harmonic in the series representing a rectangular wave is $1/n$ it follows that the ratio between the amplitude of the nth harmonic and the fundamental is

$$\frac{M_m}{M_f} = \frac{\dfrac{\sin\left(S \dfrac{n\,\alpha}{2}\right) \cos \dfrac{n\,\gamma}{2}}{S \sin\left(\dfrac{n\,\alpha}{2}\right)}}{n \dfrac{\sin S\,\alpha/2}{S \sin \alpha/2} \cdot \cos \gamma/2}$$

Denoting this ratio by C_n, the rotating magnetomotive force of an induction motor is in general

$$M\,(\sin x + C_3 \sin 3\,x + C_5 \sin 5\,x + C_7 \sin 7\,x, \ldots)$$

where M is the amplitude of the fundamental.

If the pitch deficiency is so chosen that $\dfrac{n\,\gamma}{2}$ is approximately equal to 90 deg. or an odd multiple thereof, $\cos \dfrac{n\,\gamma}{2}$ is very small and the nth harmonic will disappear or be greatly minimized. The harmonic of lowest order traveling in the same direction as the fundamental, that is the 7th in the three-phase and the 5th in the two-phase, is usually the most effective in producing depressions in the speed-torque curve in the range of speed from standstill to synchronism; and if the application is such that only this part of the curve has to be considered, the objectionable harmonic can be eliminated as shown.

However, on the part of the speed torque curve below standstill, or backward rotation, it is usually the harmonic of lowest order traveling in opposite direction which is most effective and therefore becomes of importance if the motor is used for braking purposes or reversing service.

Obviously, the pitching can not always be so chosen as to eliminate two harmonics, and it then becomes desirable to predetermine the effect of each to make sure that the motor has sufficient torque at all speeds to do the required work. Furthermore, the winding pitch giving the most favorable conditions from standpoint of harmonics, may not be the most desirable one from the standpoint of performance, and should then not be used unless the torque components are sufficiently large to justify the sacrifice in performance.

All the magnetomotive forces of the primary set up fluxes of greater or less magnitude, and if the rotor currents can distribute themselves freely, a condition approximately realized in squirrel-cage rotors, there are components of secondary current corresponding to each of these flux waves. The amplitude of each wave depends on the m. m. f. producing it, the reaction of the secondary current caused by it and the reluctance of the path.

The flux density set up by any harmonic is evidently a maximum when the rotor passes through the synchronous speed of that harmonic, because at that point the component of secondary current opposing its m.m.f. is zero. As the rotor speed decreases below or increases above this point the corrective currents in the secondary rapidly reduce the flux waves due to the harmonics.

The primary current, depending chiefly on the reaction of the rotor current corresponding to the fundamental wave can be calculated in the usual way for any rotor speed.

Let C_n = the coefficient of the nth harmonic in the m. m. f. series
I = primary current
I_n = n th harmonic component of secondary current in terms of primary
$-j\,X_0$ = Mutual reactance between primary and secondary in terms of primary.

N = Synchronous speed corresponding to nth harmonic

S = Rotor speed

s = $\dfrac{N - S}{N}$

z = $r - j\,s\,x$ = secondary impedance in terms of primary, the end-ring resistance being calculated for the number of poles of the nth harmonic, x is the reactance due to the secondary slot and zig zag leakage fluxes. The primary current I is taken as parameter.

The currents which combine vectorially to produce the resultant m. m. f. of the nth harmonic then are

$$C_n I + I_n/n$$

and since the flux wave of this harmonic rotates with a velocity equal to $1/n$ that of the fundamental, the secondary voltage at standstill is

$$e_n = \frac{j\,X_0}{n}\,(C_n I + I_n/n)$$

and at the rotor speed S the secondary current, is

$$I_n = \frac{s\,e_n}{z} = \frac{j\,s\,X_0}{n\,z}\,(C_n I + I_n/n)$$

Solving for I_n

$$I_n = \frac{j\,s\,X_0\,C_n\,I}{n\,z - j\,s\,X_0\;n}$$

Substituting $r - j\,s\,x$ for z

$$I_n = \frac{j\,s\,X_0\,C_n\,I}{n\,r - j\,n\,s\,x - j\,\dfrac{s\,X_0}{n}} = \frac{j\,s\,X_0\,C_n\,I}{n\,[\,r - j\,s\,(x + X_0/n^2)\,]}$$

Substituting this value of I_n in the formula for e_n

$$e_n = \frac{j\,X_0}{n}\left[C_n\,I + \frac{j\,s\,X_0\,C_n\,I}{n^2\,[r - j\,s\,(x + X_0/n^2)\,]}\right] = \frac{j\,X_0\,C_n\,I\,(r - j\,s\,x)}{n\,[r - j\,s\,(x + X_0/n^2)\,]}$$

Let $\quad a = x + X_0\;n^2$

$$I_n = \frac{j\,s\,X_0\,C_n\,I}{n\,[r - j\,s\,a]}$$

$$e_n = \frac{j\,X_0\,C_n\,I\,(r - j\,s\,x)}{n\,[r - j\,s\,a]}$$

The torque in synchronous watts is the real component of the product $e_n\,I_n$ and in lb-feet the torque is $T = 7.03/N \times$ Synchronous watts, hence

$$T = \frac{7.03\,p}{N}\,[e_n\,I_n]_{real} = \frac{7.03\,p}{N}\left[\frac{j\,X_0\,C_n\,I\,(r - j\,s\,x)}{n\,(r - j\,s\,a)} \cdot \frac{j\,s\,X_0\,C_n\,I}{n\,(r - j\,s\,a)}\right]_{real}$$

where p is the number of phases.

Multiplying out, keeping in mind that this product is a double frequency quantity and multiplication by j changes the sign, and reducing

$$T = \frac{7.03\,p\,C_n^2\,X_0^2\,I^2\,s\,r}{N\,n^2\,(r^2 + s^2\,a^2)}$$

To find the value of s for which the torque becomes a maximum differentiate $\dfrac{s\,r}{r^2 + s^2\,a^2}$ with respect to s and equate to zero as follows:

$$\frac{d}{d\,s}\left[\frac{s\,r}{r^2 + s^2\,a^2}\right] = 0$$

$$r^2 - s^2\,a^2 = 0$$

$$s = r/a$$

Substituting this value for s in the torque formula the maximum torque due to the nth harmonic is

$$T_m = \frac{7.03\,p\,C_n^2\,X_0^2\,I^2}{2\,N\,n^2\,a}$$

Writing $x + X_0/n^2$ for a the maximum torque is

$$T_m = \frac{7.03\,p\,C_n^2\,X_0^2\,I^2}{2\,N\,n^2\,(x + X_0/n^2)}$$

The mutual reactance is approximately E/I_0 at low density, where E is the impressed voltage and I_0 the magnetizing current corresponding to this voltage. Since the magnetizing current at low saturation varies directly with the effective air gap, it follows that X_0 varies inversely with the gap.

Since X_0^2 appears in the numerator of the torque formula, it follows that increasing the air gap is an effective way of reducing the torque due to higher harmonics and thus minimize the tendency to sub-synchronous speeds. Experience has shown this to be the case. Furthermore, I is large when the self inductive impedance of the motor is low, and the combination of large mutual reactance and low impedance is characteristic of motors of low number of poles in which experience has shown that the tendency to sub-synchronous speed is most prevalent.

As illustration, consider a 15 h. p. 220 volts, three-phase, 60-cycle, two-pole motor of the following constants.

$X_0 = 66$			$x = .5$
	5th	7th	11th
r	$= 0.335$	0.313	0.291

The motor has 36 slots and the pitch is $1 - 14$ or 5 slots pitch deficiency, hence

$$S = 6 \quad \alpha = 10° \quad \gamma = 50 \quad \text{and}$$

$$C_n = \frac{\dfrac{\sin 30\,n}{6 \sin 5\,n} \cos 25\,n}{n \dfrac{\sin 30}{6 \sin 5} \cos 25}$$

$$C_5 = 0.0372 \quad C_7 = 0.023 \quad 8\,C_{11} = 0.0106$$

Only the numerical value of C_n need to be considered since the rotation of the flux wave is the same whether the sign of C_n be positive or negative.

The fundamental torque curve and primary current are shown in Fig. 1.

In the 5th harmonic the slip at which the maximum torque occurs is

$$r/a = \frac{0.335}{0.5 + 66/25} = 0.107$$

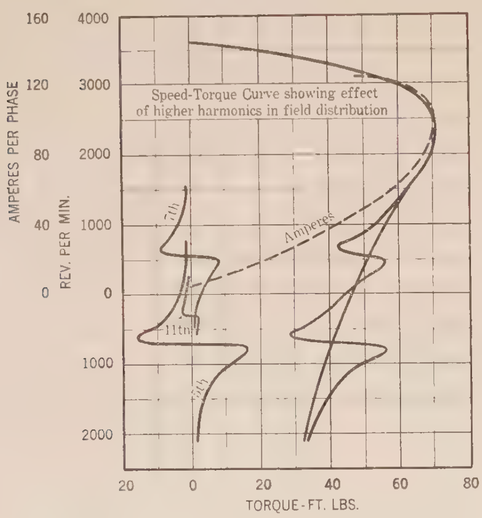

Fig. 1—15 Horse Power, 220 Volts, Three-Phase, 60-Cycle, Two-Pole Induction Motor

The synchronous speed of the 5th harmonic is 720 rev. per min. and 10.7 per cent slip is 642 rev. per min. and at this speed the primary current is 122 amperes per phase, hence the maximum torque is

$$T_m = \frac{7.03 \times 3 \times 0.0372^2 \times 66^2 \times 122^2}{2 \times 720 \times 5^2 \times 3.14} = 16.4 \text{ lb-feet}$$

In Fig. 1 are shown the torque curves due to the 5th, 7th and 11th harmonics and their effect on the fundamental torque curve. It will be noticed that in a range of speed from about 450 to 600 rev. per min. the torque varies over quite a wide range with comparatively little change in speed. This was verified on actual test, the torque could be varied considerably without the motor speeding up or coming to a standstill.

Fig. 2 shows the speed torque curve of a 40 h. p. four-pole motor with full pitch winding and Fig. 3 shows the curve of the same motor with the winding fractional pitched one slot. With the winding fractional pitched two slots the torque components of the higher harmonics are so small as to be practically negligible in this particular case.

An increase in the secondary resistance increases

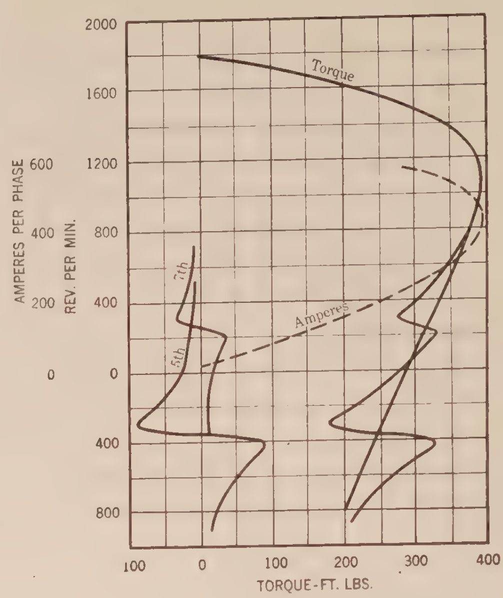

Fig. 2—40 Horse Power, 220 Volts, Three-Phase, 60-Cycle, Four-Pole Induction Motor

the torque of the fundamental where the sub-synchronous speed is likely to occur, while the maximum torque of the harmonic is unchanged, and the resultant torque is therefore increased.

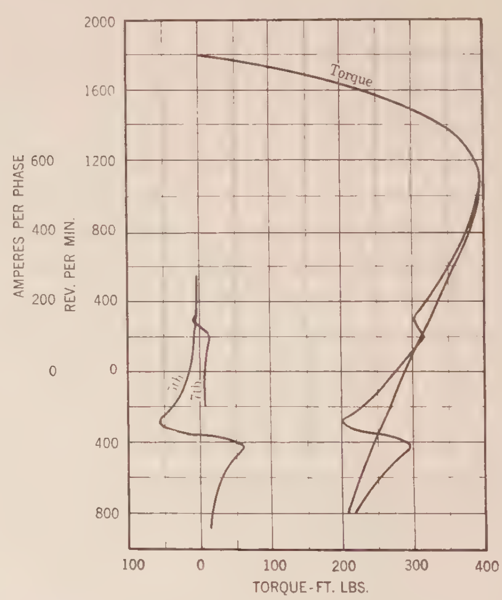

Fig. 3—40 Horse Power, 220 Volts, Three-Phase, 60-Cycle, Four-Pole Induction Motor

Unsymmetrical grouping of the coils will undoubtedly also produce modifications in the speed torque curve, but this discussion applies to symmetrical windings only.

Influence of Temperature on Insulating Materials Used in Electrical Machinery

BY ERNESTO VANNOTTI

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Laboratory tests, as well as the condition of machines which have been running a number of years, show that the temperatures that can be withstood without damage to the insulating materials are considerably higher than those prescribed by international rules.

The present values have probably been chosen so as to guard against too high temperatures caused by defective construction of certain parts of the machines.

If exploring coils are placed suitably and with care at the points where overheating is most likely to occur, the value of the permissible temperature, as recorded by the coils, should be 10 to 20 per cent higher than the rules permit, in order fully to utilize the materials of construction. Windings for over 5000 volts should not contain any air pockets.

THE influence of temperature on insulating materials is a question of great importance which is to be discussed by the American commission for the standardization of electrical machinery, to which electrical engineers of various countries have been invited. It is much to be desired that a thorough investigation of the subject might lead to the acceptance of the same standards by different countries, so far as these standards concern the permissible temperature rise compatible with the present state of development in the maunfacture of insulating materials.

The president of the commission of Italian electrical engineers asked me to prepare a paper on this subject. However, I must call attention to the fact that the subject is very extensive and involved, and that causes of heating of the insulated portions of the machines, as well as of the insulating materials themselves, may be exceedingly numerous and complicated. I am therefore unable to enter into a detailed discussion, or to compare thoroughly the properties of the different materials used, but will only attempt to give a general survey and summarize the conclusions, which, it seems to me, can be drawn from practise.

Laboratory tests, and the process of manufacture of different insulating materials and insulated windings have shown that the insulated conductors used for electric machines are capable of withstanding, without damage, temperatures which are appreciably higher than the maximum values laid down by the International Electrotechnical Commission.

This observation is borne out by the fact that insulated current-carrying parts of many machines—the temperature rise of which corresponds to standards approximately in accordance with those now prescribed by the International Standardization Rules—are still in excellent condition after 20 years' service, even in cases when notable overloads occur. In other words, the running of these machines for a long time, which corresponds to a continuous service lasting at least 10 to 20 weeks, with temperatures 20 to 30 per cent greater than the maximum values now allowed by international standards, has scarcely affected the structure and dielectric strength of the insulating material.

Practise has shown, moreover, that machines whose temperature rise, measured by the increase of resistance of the windings, remains within the limits allowed by International Standards, are sometimes liable to failures after a comparatively short time on account of excessive temperature rises which cause failures to occur in parts of the winding. As an example, I may mention the case of a three-phase, 6000-kv-a. turbo-alternator, at 1500 rev. per min., 6250 volts, 580 amperes, 50 cycles. The stator is well ventilated and has bar winding of massive copper as shown in Fig. 1. This winding should have an average temperature rise of 60 deg. cent. according to the method of measuring the increase of the resistance. Nevertheless, the insulation was damaged after a certain time on account of the abnormal temperature rise of the bar placed nearest the air gap. The small iron wedges which partly close the slots of the stator are evidently much too small to prevent or dampen to any great extent the variations of the magnetic field in the copper bars. For this reason, large eddy currents occur which entail excessive local heating and consequent damage to the insulation. The copper bar near the air gap was replaced by a stranded conductor composed of a great number of fine wires. Although the copper cross section was 20 per cent less than the section of the solid copper bar, no further damage occurred to the insulating material under the same operating conditions.

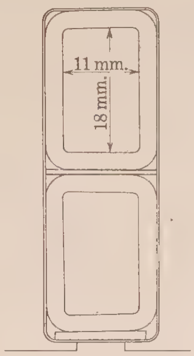

FIG 1.

With high-voltage windings for 5000 volts and over (and occasionally for 3000 volts), it is well known that, if air is present between the individual coils on account of breakages in the insulation, damage is likely to occur as though the temperature rise had been excessive, notwithstanding the fact that the latter is well within the prescribed limits. In this case, the harm to the insulating material is caused by the formation of ozone which is produced by static discharges in the air gaps between the coils.

Displacements of commutator segments have been known to arise, even when the commutator appears to be correctly designed, which entail sparking at the brushes. This occurrence is due to insufficient attention having been paid to the expansion caused by heating.

It appears, therefore, that abnormal temperature rises, or occurrences met with in practise which are due to constructional shortcomings prejudice the preservation of the insulation in service. Furthermore, it is not always possible to discover these faults or their origin during acceptance tests.

The precise determination of these conditions forms part of the programme of the committee appointed to determine the permissible temperature rises. In my opinion, the existing values have been chosen unnecessarily low so as to insure against concealed faults in construction.

I think that it is pertinent to give an example, which, although not directly related to the subject under discussion, is of certain importance as it serves to confirm my statement that the tendency is to prescribe stringent acceptance tests in order to guard against any unforseen circumstances.

At a meeting of the Italian Electrotechnical Commission the following motion originating with a foreign association was discussed: "Insulation tests for turbo-alternators, contrary to those for ordinary machines, should comprise a pressure test for pressures corresponding to three times the working voltage, since this particular class of machines is most likely to be damaged by insulation failures." I cannot understand the reason for this special treatment of turbo-alternators, and consider that the recorded damage to the insulation is due rather to constructional shortcomings than to insufficient insulation, or to an insulation test that was not severe enough.

In reality, I believe that insulation failures of portions of conductors embedded in the stator iron are caused by excessive local overheating of these conductors, similar in fact, to the case of the 6000-kv-a. turbo-alternator already mentioned. With conductors of ordinary dimensions, that is to say, those having sections sufficient to preclude eddy currents, special precautions have to be taken to prevent local overheating which may be sufficient to cause the best micanite insulation to deteriorate rapidly.

Defects of windings situated outside the stator iron, especially where the conductors leave the iron core, are most probably due to mechanical imperfections, which are easily produced by short circuits or false parallel connections when the end windings outside of the stator core are not properly secured and braced.

I will, therefore, go a step further and assert that the running conditions will be less satisfactory in the case of a machine which has been damaged through one of the reasons just enumerated, and has been rebuilt so as to be able to withstand a test voltage of three times the operating voltage, without altering the principles of its construction. The reason for this is to be found in the excessive thickness of the insulating layers of the parts embedded in the stator which have been renewed with the consequently increased difficulty of ensuring efficient cooling—a problem which has always needed great care with turbo-alternators. If the distance between end connections is augmented in order to allow a test pressure equal to three times the operating pressure to be withstood without reinforcing their supports, the mechanical stresses, damage to the insulation, etc. will be increased on account of the greater distances and higher electromagnetic stresses in the end connections.

I consider, therefore, that the allowable temperature rises prescribed by international standards are too low for machines which are designed and built correctly. These standards, moreover, do not permit the active material of electric machines to be fully utilized, and consequently increase the cost of manufacture.

Moreover, it is logical that excessive local overheating should be objected to and that its cause should be found out during the acceptance tests in order to obtain a guarantee from its after effects. The occurrence of abnormal local overheating can be revealed by inserting exploring coils in places which are most likely to overheat. It goes without saying that these thermo-indicators must be manufactured and put in place with care so as to preclude errors of measurement.

Finally, I should like to make the following suggestions:

1. If the temperature rise is measured by suitably placed and reliable thermo-indicators so that no doubt exists as to the correct measurements of the temperatures at the hottest parts of the machine, new figures should be prepared for the international standards giving the highest permissible temperatures in such cases, the values of which should be 10 to 20 per cent higher than those now allowed.

2. All windings for voltages greater than 5000 volts must be provided with impregnating material in order to prevent air spaces between the individual conductors and the different layers of insulating material.

3. Commutators should be allowed to run at a maximum temperature of 115 deg. cent. provided that no deformation or sparking occurs at this temperature.

WIRELESS WAVES FOR UNDERGROUND COMMUNICATION

Tests conducted at the experimental coal mine of the Bureau of Mines at Bruceton, Pa., hold out the hope that wireless waves may be used in the future as a means of effective communication between rescuers on the surface and miners entombed in mines following fires and explosions. These preliminary experiments of the Bureau of Mines, while failing to develop any practical method of using wireless waves for underground communication, nevertheless indicate clearly that electromagnetic waves may be made to travel through solid strata. In the Bruceton experiments, signals were heard distinctly through fifty feet of coal strata, although the audibility fell off rapidly as this distance was increased. The absorption or loss of intensity with distance is very great for the short wave lengths used in these tests. Longer wave lengths are known to suffer less absorption and may possibly be found practically effective under certain conditions.

Technical Committee Annual Reports, 1921-1922

(*Concluded from page 912 of* JOURNAL *for November, 1922*)

COMMITTEE ON TRANSMISSION AND DISTRIBUTION

(*Continued*)

In the February 1921 issue of the JOURNAL, Mr. Philip Torchio presented a paper on "Permissible Operating Temperatures of Impregnated Paper Insulation in which Dielectric Stress is Low."

After a review of the effect of temperature on insulating materials, abstracting from the 1913 Steinmetz and Lamme Report, and the 1905 British Engineering Standards Committee tests, the author questions the present temperature limit adopted for impregnated paper when used for low-tension cables. Results obtained from surveys of low-tension cables in large distributing systems, and also the results of special tests on cables including sheath cracking, high temperature tests, effect of bending on cables heated at high temperatures and distillation of cable compounds are shown and discussed. The vital importance of ambient temperatures in subway ducts as affected by the thermal conductivity of concrete, amount of moisture in the soil, different arrangements of ducts, and load factors at which the cables are operated, is pointed out. The conclusions derived by the author are that the permissible operating temperatures are to be a function of the load factors at which the cables operate, and he recommends 105 deg. cent., 95 deg. cent., and 90 deg. cent., for load factors of 33 per cent, 50 per cent, and over 66 per cent respectively.

In the same issue of the JOURNAL Mr. L. L. Elden has also contributed a paper on "Permissible Operating Temperatures of Impregnated Paper Insulation in which the Dielectric Stress is Low."

The conditions considered in adopting 85 deg. cent. as the limiting conductor temperature for impregnated paper-insulated, low-tension cables are discussed and conditions which hazard the safety of the cable when operated at the higher temperature limits are pointed out. The results obtained by a large operating company, one whose cables the limiting temperature of 85 deg. cent. has not been exceeded, are described and discussed. The practicability of operating cables on a load factor basis, or by specifying an allowable overload rating in terms of temperature is questioned. The conclusion drawn is that a conservative standard, such as the present Standard rule, is the more desirable policy.

A paper entitled "The Maximum Safe Operating Temperature of Low-Voltage Paper-Insulated Cables was also presented in the same issue of the JOURNAL by Mr. W. A. Del Mar.

The mechanical strength of low-voltage cables is discussed and a tearing test for paper is described. The results of experiments made to determine the effect of continuous heating are given and indicate that the mechanical strength of paper insulated cables is destroyed by continuous exposure to a temperature of 100 deg. cent. for three or four weeks. The author believes the operation of cables at higher temperatures than that allowed by the present Standards is in the nature of a gamble and questions whether the Standards should take cognizance of it.

Mr. Wallace S. Clark contributed a paper entitled "Notes on the Effect of Heat on Impregnated Paper from Cable Insulation."

This paper covers tests made to determine at what temperature marked deterioration in the paper of impregnated paper cable took place. The tests are described and the results given and discussed. The conclusion drawn is that the temperature limit fixed for the operation of a low-tension cable, to avoid undue deterioration, must take into consideration the length of time during which temperature is maintained.

E. B. MEYER, *Chairman.*

TRACTION AND TRANSPORTATION COMMITTEE REPORT

To the Board of Directors:

In conformity with the President's request for a discussion of some phases of the conditions prevailing in the field covered by this Committee, we beg leave to submit the following:

The year has been practically devoid of large or interesting developments in the electric transportation systems in the United States. The use of the one man car, trackless trolley and the motor bus has become more general in the light traction field but in heavy equipment construction activity has been limited almost wholly to foreign countries.

The introduction of important new or novel ideas in traction equipment also has been largely lacking and those engaged in engineering in this field appear to have been occupied mainly in efforts to standardize and perfect equipment of existing types and to adapt them to special local conditions.

In the face of such a situation, we have found a dearth of technical material for subjects of papers and discussions that did not promise to degenerate into a rehash of old and threadbare questions. Exhaustive treatments of electrification of steam railroads such as that presented in the recent Super Power Report have covered very completely most of the technical aspects of this problem. The question then naturally arises whether the limitation of the Institute's papers and discussions to more or less technical electrical detail subjects is either wise or a full performance of our duty

as a trained body of men with special information at our command which might be beneficial to the public if presented in a form readily grasped. Is there not a further obligation upon us?

Is there not an equal duty laid upon us to give to others not technically equipped a clearer view and better understanding of great public questions which to be wisely solved must be based on a sound engineering foundation? Is it right to confine our papers and discussions to the engineering detail technique of great subjects for the sole benefit of our own and our professional brethren? By such a procedure do we not stand aloof from the great national and world problems creating the impression that we do not comprehend their wider phases or are timid about venturing beyond our own limited self-prescribed professional boundaries?

Take for instance the steam railroad situation as it is before the country today and the bearing of electrification thereon. We have had ream upon ream of papers and hours without end of discussion of direct vs. alternating traction and coal economy of, steam vs. electric engines.

How often have we gone below the surface and discussed the function of railroads as a necessity in the life of our country (the United States) and the fact pointed out by such far-seeing men as President Willard that in the immediate future it is not a question of rates but a question of capacity which we face when business shall again become normal?

There is no longer need for technical discussions of whether electric traction will add capacity to a given railroad track system; that is admitted, demonstrated, and settled. Practically every steam railway in the country has an electrification problem of some sort under consideration and on the larger systems there are many such.

To carry them out and to make possible any general advance toward a wider use of electric traction on our great national arteries, public opinion must first be awakened to the basic economic facts and a general nation wide realization must be created of the necessities of these systems. A clear conception of the fundamental function of these railway lines to the nation as well as the effect upon general business of their failure to keep in step with the growth of the country is not easily acquired and yet it must come before we can secure full financial support for the program which must come before long. The Chairman of the Joint Committee of Congress recently stated as follows:

"We believe that the transportation facilities of the country must be placed upon a solid foundation. It will not do to make up deficits by appropriations of public funds. The railroad companies must be operated with the expectation that the gross revenues will be sufficient to cover operating expenses and leave a reasonable return upon the investment. It is of paramount importance to the public welfare that the transportation companies be made going concerns; that they be placed upon a substantial foundation in every respect, and that the operating expenses be reduced by careful and efficient management."

Is not this news to many people and is the situation not one warranting our best analysis?

The engineer has a trained mind familiar with the physical facts of this subject, he has acquired the habit of straight honest thinking step by step from premises to conclusion, why should he not broaden out his field and embrace the opportunity to inform and build up public opinion upon sound facts and impartial criticism.

There are many engineers who are members of this Institute who seldom or never appear or take part in discussions because their field has broadened and they no longer deal with details. Why should we not bring in these men and popularize, if you please, for the benefit of the public this subject so that by our keen logic of presentation of the economic facts we may attract the attention and interest of the mind of the man on the street.

Here is a really big subject of vital importance to the life and prosperity of the nation. We have the training and the knowledge, why should we not step outside the narrow confines of our technical field and show that engineering is more than handling kilowatts and kilovolts, that it is and must ultimately be the controlling factor in the economics of many natural problems if they are to be solved permanently.

H. W. Brinkerhoff, *Chairman*

TELEGRAPHY AND TELEPHONY COMMITTEE

To the Board of Directors:

During the past two years the Institute has to an increasing extent served as a clearing house for information dealing with technical advances in telegraph, telephone and radio engineering, one direct result of which is the rapidly growing number of communication engineers applying for membership in the Institute.

Electric communication engineering in all its branches made marked progress during the war years and the improvements made to meet the needs of war have as rapidly as economy permitted been applied to the needs of peace time and of commerce.

One of the features of the committee's plans which has been followed closely is that of providing for the presentation of technical papers at meetings of the Institute giving detailed information of the noteworthy advances made in the various departments of the art. It may safely be stated that the present progress of communication in all its branches is recorded in the various papers published in the Institute Journal during the past two or three years.

Protective Devices

It has been suggested that the Protective Devices Committee of the Institute might to advantage include in its investigations a study of the problems of communication line and apparatus protection against lightning disturbances and accidental contact between power wires and communication wires. The subject

has been given engineering consideration by individual companies but a wide diversity of devices is used on lines throughout the country and it would seem that there is opportunity for standardization of devices to meet like conditions in various localities, both in railroad and commercial line operation, telegraph and telephone.

Inductive Interference Prevention

The movement mentioned in last years report of increasing cooperation in studying the needed procedure in the coordination of signal and power circuits has gone forward with growing impetus during the present year. This effort is general among all of the utility interests concerned and reflects a recognition on all sides of the mutual nature of the problem and of the duty of all to so harmonize their facilities as to afford the public the various services that it needs, with convenience and economy.

Several committees have been actively engaged in studying various phases of the inductive interference problem, some being joint committees formed upon the invitation of state regulatory bodies, others being established by groups of public service companies. The purpose, in general, has been to develop a more comprehensive understanding of the subject and to make available systematic working principles and standards for guidance in field practise.

In this direction, perhaps the most prominent work of national scope has been done through the cooperative efforts of the American Telephone & Telegraph Company representing the Bell Telephone System, and the National Electric Light Association. A joint committee of these two interests is conducting studies for the purpose of preparing comprehensive principles and practises of coordination for the guidance of the associated operating companies in planning the location, construction and operation of their facilities. Two progress reports thus far issued embody rather complete principles of inductive coordination and encourage the expectation of further constructive results toward solving the inductive interference situation.

On all sides there is a growing realization of the importance of maintaining a broad view to the future and of consulting cooperatively in advance on the development of plans for contemplated plant extensions.

The committee has not learned of the advent during the year of any outstanding new devices applicable to the prevention of inductive interference.

Automatic Telephony

The further installation of automatic telephone exchanges has continued during the past year. At Omaha, Nebraska, a panel automatic plant was placed in service in December, 1921. During the year automatic exchanges have been built in accordance with predetermined policies as to design. There is, however, nothing particularly new to report in the way of engineering change.

Printing Telegraphs

The Western Union Telegraph Company has continued to increase the number of its circuits operated by multiplex printer methods. In many places all of the circuits operated into an office are "printer"—no manual Morse circuits being worked at these points. The extension of printing telegraph systems has necessitated opening additional repeater stations, but this is an economy in view of the increased volume of words in a given time which may be handled over a wire properly spaced with repeaters.

During the year the Postal Telegraph-Cable Company once more has placed a printing telegraph system in service on certain New York-Chicago circuits. The system is the Morkrum Multiplex. The Postal Company has been operating manual Morse exclusively since early in 1919, at which time the printer duplex system then in use was discontinued.

Radio Telegraphy

Trans-oceanic commercial radio telegraphy has continued to improve in reliability, with the natural result that the volume of traffic has steadily increased. Radio duplex channels now are continuously operated between New York and stations in England, France, Norway, Germany, with stations soon to be opened in Sweden, Holland, Italy and Poland. The station of the Radio Corporation of America, at San Francisco, works continuously with stations in Hawaii and Japan.

A noticeable tendency is to employ vacuum tube oscillators for transmission, both for telegraphy and telephony.

On the Pacific Coast continuous radio telegraph service is performed by a commercial company between the cities San Francisco, Los Angeles, San Diego, Tacoma, Portland and Seattle. A large volume of business is handled in competition with the wire companies.

Radio Telephony

One of the most spectacular developments during the year has been the application of radio telephony. This art has advanced rapidly, along technical and scientific lines for several years, and today many startling demonstrations, of special circuits, instruments of high sensitivity, special amplification and accurate modulation are in use. This valuable scientific work has of course been continued, but the committee wishes to report, this year on the engineering development of the art.

Although several scientific developments and inventions could be recorded the great work has been the extensive application of radio telephony, increase in efficiency, power and quality of transmission, and the increase in efficiency and simplification of receiving equipments to meet the great demand of the general public for telephone reception in the home.

The regular public broadcasting of news, church services and entertainment from the Pittsburgh district created nation wide interest in radio broadcasting and within the year the manufacturers and distributors of radio apparatus have started additional regional broadcasting service from large radiophone stations, giving news, music, speeches, church services, grand opera, athletic events, market reports, etc.

The fascination and value of radio telephone broadcasting service in the city, home and on the isolated farm has created such a demand for telephone receiving equipment that an active industry has grown up within the year.

The design and production of high efficiency instruments suitable for the novice, with simple operation, and suitable in appearance for the living room, has been an engineering development worthy of note, and it is felt that the great activity in this art justifies the present extensive engineering development to meet the large future application of radio telephony.

Railroad Telegraphy and Telephony

Plans for additional railroad intelligence transmission reflect the general interest in radiophone developments. Operating departments have expressed a need for a simple, reliable and comparatively inexpensive radiophone equipment. It is anticipated that such sets will have a field in train operation for communication between caboose and engine. Today railroad trains a mile long are quite common and there is a positive need for communication between conductor and engineer on such trains.

Also there are possible applications for portable radiophone sets for use in bridging gaps temporarily when washouts or floods destroy pole lines carrying wires.

At large seaports the railroad companies maintain extensive fleets of tugs and it is found that radio telephony affords an opportunity to maintain continuous communication between tug captains and tug dispatchers.

The Telegraph and Telephone Section, American Railway Association during the year completed reports dealing with "Telegraph and Telephone Transmission," "Wire Crossings," and "Education and Training of Telegraph and Telephone Employees."

A technical development of the year was the introduction of a vacuum tube rectifier used to transform alternating current into direct current at 80 to 400 volts.

Aerial Cables

Further extension of the aerial cable plant of the American Telephone and Telegraph Company includes a section between Harrisburg and Pittsburgh, Pennsylvania, a distance of about 200 miles. This cable provides approximately 300 telephones and 175 telegraph circuits.

Submarine Telephone Cables

On April 11, 1921, commercial telephone service was inaugurated between the United States and Cuba, over three submarine cables laid across the Florida Straits between Key West, Florida and Havana, Cuba. These submarine cables are the longest and most deeply submerged which are in use for telephone communication. The cables are 104.9 nautical miles (195 km.) long. These cables are loaded and vacuum tube repeaters are employed at the terminals for connecting land lines to the cabled circuits. In addition to the telephone facilities provided, conductors in the cable are used also for direct current telegraphy and for carrier current telegraphy—over the latter four-channel multiplex printers may be operated.

Pneumatic Tubes in Telegraph Service

In large cities it becomes necessary to establish branch offices in addition to the main telegraph office, so that the public may have convenient access to the telegraph. In the business districts the volume of traffic at some branches, if handled by wire, would necessitate the use of a large number of circuits to the main office with operators at both ends of each circuit, in order to move the traffic promptly under normal load conditions. To handle peak loads or abnormal rushes would require additional wires, equipment and operators, that would be idle a greater part of the time.

This has led to extensive use of underground pneumatic tubes between the main office and the more important branch offices. Tubes are generally laid in pairs in order to handle traffic in both directions simultaneously. While the initial installation is expensive, the annual charges are found to be less than the cost of handling large numbers of messages by wire.

The load limit of a tube is seldom reached, even during abnormal peaks, since the power required to move the carriers containing messages is a small part of the total power required to move the carriers and the air column in the tube. Approximately constant speed of service can be maintained under varying traffic conditions. In addition, chances for errors in receiving and in re-transmitting the message are eliminated.

Tubing of 2¼ inches inside diameter has been standardized as most suitable for telegraph service. The terminal equipment and carriers are not too bulky, yet the carriers are large enough to contain a considerable number of messages. Outbound tubes are operated under pressure and inbound under partial vacuum, the power supply usually being at the main office end.

The outer ends of a pair of tubes are joined together to permit the circulation of the same air repeatedly. This tends to reduce condensation in the tubes, and, in case of stoppage, allows pressure to build up behind the carrier at the same time increasing the degree of rarefaction ahead of it.

Power is supplied by reciprocating air compressors for large systems, and by rotary pressure blowers for small systems. Compressors are driven by electric motors through short belt drives with idlers. Rotary blowers are usually mounted on sub-bases with their driving motors and connected through special worm gearing. Compressor systems are operated at 5 to 10 lb. gage pressure and 10 to 18 inches of mercury vacuum. Blowers range up to 3 lb. pressure and 6 inches vacuum. Separate blowers are used for each tube pair with "start and stop" control of the motor to reduce power consumption.

Standardization

The Report of the Standards Committee, last published, contains for the first time a representative list of terms and their definitions employed in communication engineering. Most of these definitions were prepared through cooperation of members of the Telegraphy and Telephony Committee serving on a subcommittee.

The terms now incorporated in the published report constitute a good start along this line of useful work, and the present year's sub-committee will undoubtedly add many more definitions so that in time the communication section of the Report will contain most of the terms which are of a permanent nature.

Future Activities

A year or so ago a project was submitted to the Board having in view the compilation and publication of a Bibliography of communication literature, the work mainly to be done by members of the committee. Actual work on this undertaking very likely will be delayed pending the return of more favorable printing costs.

It is noteworthy that practically all of the technical papers procured for presentation at meetings have come from members in the New York district, notwithstanding that all sections of this country and Canada are represented on the committee. It is hoped that chairmen of the various Sections will in future encourage communication engineers in their territory to prepare papers for Section presentation and for printing in the Journal. Naturally, those members who regularly attend meetings of the committee are prevailed upon to contribute or procure papers of interest. However, members remotely removed from New York should recognize the fact that papers sent in from the field are particularly welcome and should be forthcoming. It is of serious importance that members of the Institute in all sections of the country have the opportunity to present papers at meetings and that the best of these should be published in the Journal. To this end it is desirable that telegraph, telephone and radio engineers take more active interest in Section meetings.

Donald McNicol, *Chairman*

INSTRUMENTS AND MEASUREMENTS COMMITTEE

To the Board of Directors:

The following report for the year summarizes briefly the activity of the committee, a reference to articles dealing with new or essential instruments and measurements, and a brief description of new apparatus for electrical measurements that may have been designed and developed during the past twelve months.

During the year there was very marked activity abroad in the matter of standardizing rules for instruments. Several instrument specifications have been issued as follows:

England. The latest Standard Specifications of the Engineering Standards Committee are: for Indicating Instruments, No. 89, 1919, for Instrument Transformers No. 81, 1919.

France. A Proposal for Standardization of Electrical Measuring Instruments, Instrument Transformers, and Shunts was prepared by the Technical Committee of the "Chambre Syndicale des Constructeurs de Gros Materiel Electrique" and was adopted by the Chambre on Jan. 20, 1921. These rules appeared in the *Revue Generale de l'Electricite* of May 28, 1921.

Germany. Rules for Electrical Measuring Apparatus proposed by the Verband Deutscher Elektrotechnicker were published in the *E. T. Z.* of Mar. 31, 1921. Those for Instrument Transformers on Mar. 3, 1921, with changes and additions on July 28, 1921. It is proposed that these become effective July 1, 1922.

The French and German specifications were translated by Mr. H. B. Brooks of the Bureau of Standards and copies were circularized among the members of this committee and other individuals throughout the country who might be interested in the subject.

A comparative analysis of the foreign specifications shows some lack of agreement among the different countries. Apparently the rules are not to be considered final; many admittedly tentative parts are included, awaiting revision in the light of further research or practical experience. In general the rules take up questions of construction, accuracy and nameplate markings. Grades are established and requirements prescribed which apparatus must satisfy in order to be entitled to use the grade symbols. These requirements involve considerations of case protection, scale and pointer construction, damping qualities, sensitivity to disturbing influences, insulation, safety, self-heating, standard-ranges, transformer ratios, potential drops in shunts, limits of error, identification of terminals, connections, etc.

Incidentally this standardization has involved questions of terminology, definitions, the setting of standard quantities such as temperature and frequency and the conditions under which tests were to be carried out.

In view of the activity abroad along the lines of standardization for instruments, there was considerable

discussion in meeting and correspondence by this committee as to the possibility of preparing similar American rules and the ways and means for preparing and accepting them. It was finally decided that a subcommittee be appointed to canvass the sentiment, particularly of the manufacturers of instruments in this country, as to the necessity or desirability of such standards. Mr. H. B. Brooks volunteered to conduct such a canvass inasmuch as he intended to visit many of the instrument makers in this country. He was, therefore, appointed a subcommittee of one to make such a canvass and report back to this committee. This trip is still in progress and no report is available at this writing.

The committee devoted considerable time in meeting and correspondence to the consideration of standardizing certain terms of measurements and instruments relative to which there was a divergence of usage. The findings of the committee were discussed with the subcommittee of the Standards Committee on Meters, Instruments and Instrument Transformers. It was felt that the particular terms in question represented only part of a large number that might properly be considered. The matter is, therefore, held open for further consideration and action.

The committee feels that report can briefly be made of the following instruments or devices which have appeared during the past year, some of which are novel in principle and others that may be considered modifications of an old principle, applied in a different manner or placed in a more practicable form of instrument. A new design of current transformer called a "two-stage" transformer, consisting essentially of the usual primary and secondary winding and an additional secondary compensating winding to correct for the ratio and phase angle distortions encountered in the ordinary type of two winding transformer, was advanced. This transformer is being designed and developed with a view to improving the accuracy of current transformers for use with instruments and watt-hour meters. A paper by H. B. Brooks and F. C. Holtz is scheduled for presentation, which describes in detail the design and performance characteristics of this transformer.

In response to the demand for a simple inexpensive equipment for testing current transformers, numerous arrangements for making such tests have been developed. Although several of these methods are comparatively old, none has come into general use because of certain limitations, such as time required, insufficient accuracy and lack of robustness. Some of these methods utilize deflection instruments, and others employ integrating instruments for measuring the quantities involved. On the other hand, all of the precision laboratory methods now in use for measuring the constants of current transformers are based on null methods.

Dr. F. B. Silsbee of the U. S. Bureau of Standards embodied the null measurement principle in a simple method for the comparison of two-current transformers of the same nominal ratio. The method is described by him in Scientific Paper No. 309 of the Bureau of Standards. A current transformer testing set embodying the principle of Dr. Silsbee's is now available. The ratio and phase-angle of the transformers being tested are determined by comparison with a standard transformer, the calibration of which has been determined previously by some absolute laboratory method.

What the instrument actually measures is the differences in ratio and phase-angle between the transformer being tested and the standard transformer. It is important to note that the instrument measures differences because difference measurements can be made with much greater accuracy than absolute measurements.

One of the makers of recording instruments reports the development of a new movement in a round chart electrical recording instrument, consisting essentially of a coil acting as a solenoid with the core located in a horizontal position in the center of the coil and supported on knife edges so that its motion backward and forward in the coil varies as a current flowing through the coil varies. Claim is made from tests on these instruments that a greater degree of accuracy is to be obtained over the entire scale than was formerly obtained with the similar design consisting of the movement of two coils attracted to one another. This new design is developed in recording voltmeters and ammeters.

Various devices have been used for some years to indicate phase rotation on polyphase circuits. Arrangements of a more or less complicated nature have been made up and used locally by various operating companies to serve this purpose, but during the past year a manufacturer has developed and placed on the market a phase-sequence indicator. This is a device in small compact portable form, consisting essentially of an arrangement of coils operating on a single lamp as an indicator. A set of directions accompanies the device, so that by two trials in connecting the binding post to a polyphase circuit, the phase rotation can be determined.

Current transformers for laboratory and portable use of the through type, permitting the threading of one or more primary turns, have been available for sometime. During the past year, however, one of the instrument makers has developed a current transformer of this type with additional self-contained primary connections which can be varied through a certain number of combinations giving an extremely wide primary range of current from 10 to 800 amperes. This transformer has, primarily been designed and constructed to give results of a better degree of accuracy than can be obtained from other preceding types of portable current transformers of this type.

The continuing necessity for an electrostatic type of voltmeter is referred to in an article by E. H. Rayner

in the *Journal of the Institution of Electrical Engineers* (British) of January 1921. Description is given of a precision form of Kelvin electrostatic voltmeter. Several mechanical and structural changes have been made in the new type of instrument with a view to eliminating known limitations and to increase the range and precision of the instrument.

One of the manufacturers reports the development of a portable frequency indicator, self-contained in a carrying case comparable with the remainder of their line of portable instruments. The armature circuit has two branches, one unaffected by changes of frequency, the other approximately resonant at normal frequency. The scale covers 90 angular degrees and gives an effective range of 55 to 65 cycles.

In the same line of portable instruments referred to above is a self-contained capacitance meter. This consists essentially of a standard condenser mounted in a case and the condenser or capacitance to be measured is compared with the standard by an armature construction equivalent to that of the power factor meter.

The very considerable activity in the field of radio transmission and reception has stimulated the design of instruments, particularly adapted to the quantities encountered in this field. Without endeavoring to list here all of the small low priced instruments for current and voltage measurements in connection with wireless equipments, developed by various manufacturers which have been placed on the market recently, reference is made to one or two devices only which seem new in principle or new in construction.

A standard radio wave meter has been designed and constructed by the radio section of the Bureau of Standards and this instrument, when calibrated, will be capable of measuring wave lengths from 65 to 85,000 meters, or in terms of frequency from 3500 to 4,600,000 cycles per second. A new type of standard inductance of the astatic principle has been developed and placed on the market.

In the field of electrical instruments for boiler or chemical measurements are the following developments. A new conductivity cell has been developed for direct insertion into a boiler drum in order that the concentration of salts in a boiler may be easily determined. The cell is constructed in such a manner that it may be safely used on pressures up to 300 lb. per sq. in. The electrodes are made of heavy nickel and the insulating structure is practically unbreakable.

The concentration indicator used with the cells may be calibrated in total dissolved solids or chlorine content. Calibration is made for the average operating pressure so that the effects of temperature variations are minimized. The advantages of this new cell are due to the elimination of sampling methods and of the necessity for extra piping to the boilers.

A thermocouple for direct insertion into a boiler under pressure has been developed. It may be installed at almost any point in the drums or headers and will safely withstand pressures up to 300 lb. per sq. in. Preliminary tests indicate that it is reliable and accurate. It is expected that this new thermocouple will be found useful for measuring variation in temperature throughout a boiler under varying loads.

A new recording meter for measuring acidity and alkalinity of boiler feed water has been recently developed. The method of measurement is based upon the determination of the hydrogen ion concentration of the feed water. The recorder operates on the potentiometer principle and records the voltage existing between two electrodes immersed in the feed.

The most important feature of the apparatus is the ability to measure actual acidity as distinguished from the total acidity determined by the usual titration methods. Actual acidity depends upon the hydrogen ion concentration and is one of the important factors involved in boiler corrosion. Another great advantage lies in the ease with which the recorder can be utilized to automatically operate signal lights or alarms to indicate undesirable conditions of the feed. Experiments are under way to determine the value of such apparatus used in conjunction with automatic valves to control the amount of alkali added to feed water, and thus maintain the alkalinity of feed within certain limits.

Considering methods of measurements rather than specific devices which may have been under consideration during the past year, reference should be made to the continued activity in analyzing and discussing methods of calibrating instrument transformers. A significant appreciation of the inherent errors in current and potential transformers is growing throughout that part of the electrical industry using instrument transformers for accurate measurements. This is confirmed by the continued development of apparatus for checking current transformers, one being referred to elsewhere in this report. Some of the central stations have equipped their testing and standardizing laboratories with instrument transformer checking equipments, these being, in general along the lines recommended and used by the Bureau of Standards. The equipment is essentially a potentiometer method, based on standard resistances and provides an extremely accurate and rapid means for calibrating instrument transformers over their entire range. It is a laboratory equipment and is not applicable for use in the field.

During the past year there appeared an article by Messrs. J. R. Craighead and C. T. Weller in the *General Electric Review* of July 1921, analyzing the advantages and limitations of the watt-hour meter method of testing current transformers for ratio and phase angle.

At the suggestion of President McClellan, inquiry has been made by your committee of various individuals in the field of activity covered by the scope of this committee for suggestions of future line of research and

investigation. Two lines of activity have been indicated.

There is apparently a demand among the central stations for an accurate and ready means of determining the character and extent of faults in cables and after the fault has been determined by measurement, there is need of some form of apparatus, preferably portable in character which will localize the fault so as to permit the cutting out and repair of the faulty section of cable. It is possible that some of the apparatus for all of the foregoing necessities falls outside of the scope of this committee. However, inasmuch as part of the problem involves measurements to determine the fault, it is advanced here as a matter of record.

In this connection reference should be made to the method of locating faults in underground cables described by Mr. Luigi Selmo in *L'Elettrotecnica* December 5, 1921. It is stated that this new scheme, tested recently, has been found very satisfactory in locating faults on the lines of the Societa Napolitana per Imprese Elettriche. The method has the great advantage of simplicity requiring only the use of two commercial type a-c. voltmeters (for instance, the hot wire type) which do not require any special instructions to set up and are easily read.

The other subject which was advanced for continued investigation and research is the question of the measurement of high potentials, particularly in view of the recent rapid increase in potentials in commercial apparatus in connection with the high voltage transmission lines. The committee does not, of course, overlook or ignore the considerable amount of very excellent work which has already been done in this direction, but with the steady extension of the previous limits of commercial voltages there arises a definite need for continued and extended activity to provide practicable, simple and accurate means for measuring these potentials.

F. V. Magalhaes, *Chairman*

LIGHTING AND ILLUMINATION COMMITTEE

To the Board of Directors:

The Committee herewith submits its report in two sections—first, activities of the Committee, and second, progress in the art.

Activities of the Committee

The Committee was appointed about the middle of October. Early in November, a "correspondence meeting" was held, by which the views of the Committee were obtained on subjects which appeared important to the Chairman. This was followed by a meeting at the Association's headquarters. At this time, the plans for the year were finally agreed upon and arrangements made for carrying them out.

Illumination Items

The principal innovation of this year's Committee is the inauguration in the Journal, of a section under the heading "Illumination Items." It is the purpose of this section to set before the membership, brief articles of interest on topics falling within the field of this Committee. It is the hope of the Committee to supply, through this channel, comprehensive, up-to-date information, in such form as to make it of greatest value to practising electrical engineers. Among other things, it is the intention to review, briefly, valuable material from other sources, which, in its original form, is too specialized or voluminous for the convenience of engineers who do not specialize on lighting.

Mr. W. M. Skiff has undertaken the compilation of material for the Committee. This section was initiated with the issue of February 1922, and already quite a number of favorable comments have been received. In the three issues published to date, the volume of text is as follows—February, page 149, six columns; March, page 223, five columns; April, page 278, five and one-quarter columns. Material in excess of the requirements of the May issue is in the Editor's possession.

In connection with this activity, the Committee has undertaken to supply the Editor, at his request, with "fillers" on lighting to be used at his discretion.

General Meetings

Dr. B. E. Shackelford was designated to take charge, for the Committee, of any arrangements for papers to be presented before General Meetings of the Association. A paper on "Glare" was presented at the Niagara Falls convention.

Section and Branch Meetings

The Committee stands ready to cooperate, so far as practicable, with sections and branches in arranging for papers on lighting. An announcement has been made in the Journal, but on account of lateness in the season, it is not anticipated that much will be done during the current year.

Lighting Progress

Lighting along with other activities was slowed down during the year 1921, due to business depression. While the lamp consumption was within 80 per cent of that of the previous year, the demand for construction materials fell off considerably more. Under the circumstances, the energies of manufacturers were naturally toward the disposal of existing stocks, rather than toward the development of new devices. The magnitude of the use of electric lighting is best indicated by the sales of incandescent lamps. In 1921, one hundred and sixty-six million large, and ninety-five million miniature lamps, were sold in the United States.

While practise in the lighting of commercial and industrial interiors is tending strongly toward general lighting from overhead locations, there are certain conditions where local or temporary lamps are required.

To meet these conditions, there has been developed a new type of mill type tungsten filament lamp, which is somewhat more substantial than any of its predecessors. Utilizing similar principles of construction, some new or improved sign lamps have also been developed. Considerable improvement has been made in the construction of the incandescent lamps for motion picture projection, and it is reported that over one thousand theatres are now so equipped.

For several years there has been under way, a development for providing a more convenient means of hanging fixtures, so that by means of a plugging device, they could be put up and taken down by novices. Since standardization is a prime requisite for such a device to insure interchangeability, an especial effort has been made to bring various inventors together. It is understood that such interchangeability devices are about to be made available by the various manufacturers of wiring devices.

This development led to the contradictory expression "removable fixtures," and the Illuminating Engineering Society has proposed the term "luminaire" as a substitute for "fixture," "lighting unit," etc.

There has been a number of developments in luminaire or fixture design. There is a marked tendency to use enclosed semi-indirect equipment, to facilitate cleaning. Also there is an increasing use of more or less dust-proof enclosing globes. The shape of such globes is tending to the flat or squat forms, in order to increase the vertical components of light and reduce the horizontal.

A number of new color-matching equipments have been designed, adapted to particular applications. There are indications of an increasing use of diffusing glassware in industrial lighting. The equipment requiring round bulb lamps is still in favor for home lighting, although some new developments, taking diffusing glassware, appear very interesting.

Not the least important development in regard to lamp equipment, is the movement toward the standardization of mechanical parts and dimensions of fixtures and glassware.

That there has been considerable activity in the installation of street lighting, is evidenced by the report that a leading manufacturer sold about 15 per cent more equipment in 1921 than in 1920. An investigation reported during the year, gives an indication of the importance of good illumination as a preventative of traffic accidents.

The general tendency has been toward better street lighting with more or less ornamental units, of which the single globe upright has been predominant. Better means have been devised for maintaining attractive appearance without sacrificing the effectiveness of light distribution. Among the important means to this end has been the use of rippled or prism glassware (with or without refractors) so arranged as to diffuse the light without largely modifying its direction.

Highway lighting is assuming a new importance, since it has been shown to be effective in promoting safety on heavily travelled thoroughfares. Moreover, the expense of such installations and maintenance is moderate, compared with the other features of construction suitable for dense and heavy traffic. Special reflectors are being developed for this service, which utilize much of the light ordinarily delivered outside of the roadway.

Outdoor sign lighting stands out on account of the rapidly increasing quantities of light employed. A year ago, relatively few outline signs were using larger than 10-watt lamps. Now, 25 and 50-watt lamps are common, while 75 and 100-watt lamps are used to a considerable extent in the large metropolitan signs.

Electric lighting of signals in streets, railway crossings and on the railway systems themselves, has made quite an advance.

In interior lighting, no application has fallen farther short of the canons of good practise than the school house, despite the fact that the welfare of the future generation was involved. Educators and others have, during the year, pointed out the need of better lighting, and reports from all sections of the country show a very keen interest in school lighting, in connection with both new and old buildings. The State of Wisconsin is the pioneer in adopting a school lighting code, although the New York Board of Education had already been requiring compliance with the Illuminating Engineering Society's code, in all schools receiving State aid.

The Illuminating Engineering Society's Industrial Lighting Code, referred to in previous reports, has been made an American Engineering Standard. This has resulted in renewed activity in several states which have not adopted such regulations.

Automobile headlighting regulations, based upon the Illuminating Engineering Society's code, are now in force in fourteen states, which represent about 50 per cent of the automobile registration of the country. About 40 per cent of the Canadian automobilists fall under similar codes in the several provinces. As a result of experience in Massachusetts, the requirements of the Illuminating Engineering Society's code has been strengthened.

In the field of research and investigation, much new data have been brought out. Some of the subjects include color temperature, ocular functions, gloss on paper, reflection characteristics of paints, and other surface finishes, refraction and interlaboratory photometric comparisons. New investigations of lighting practise in various classes of interiors have been reported.

The year has been one of activity in matters of lighting education. Lecture courses have been held in several cities and portable lighting demonstrations have been exhibited in a large number of places. An excellent example of a permanent lighting demonstra-

tion at the Massachusetts Institute of Technology has exerted a perceptible influence on the practise in that part of the country.

G. H. Stickney, *Chairman*

POWER STATIONS COMMITTEE

To the Board of Directors:

The Power Stations Committee was appointed somewhat late in the administrative year, which naturally handicapped its activities. However, the report of last year's committee was so comprehensive and complete that it is probably unnecessary and perhaps undesirable to try to attempt a similar kind of report so soon thereafter.

In past years there has been some overlapping of subjects by committees of the various national societies. In order to eliminate duplication of effort as far as is thought advisable, a group of chairmen of committees dealing with power station subjects in the various national societies was called together at the invitation of President McClellan for the purpose of coordinating their work. At this meeting an informal committee was formed of those present with the Institute Power Stations Committee's chairman as the chairman of this Committee on Coordination.

At the conference it was generally agreed that while the N. E. L. A., A. E. R. A. and A. E. I. C. committees dealt particularly with new developments and their application in electric power and railway fields, with special emphasis on desirable developments as determined by experience, the Institute committee should deal more particularly with the technical and scientific side of the problems involved in the design and use of equipment. When such problems arise in the work of the committees of the N. E. L. A. and similar bodies, the chairmen of those committees will refer such problems to the Institute committee for attention. The agreement of all of the chairmen at the conference to this plan should insure a proper coordination of the work and allocation of the various phases to the proper society. It is the intention in the annual reports of the Power Stations Committee to call attention to some of the more interesting developments described more fully in the committee reports of these other societies. However, such reports are usually not issued until May or June and it will therefore be difficult to embody these references in a report presented to the Institute at its summer meeting. This suggests the desirability of having some of the Institute committee reports presented at a later meeting in the year.

In addition to the above, the committee has aided the chairman of the Meetings and Papers Committee in the selection of papers on power station subjects for presentation before Institute conventions.

R. F. Schuchardt, *Chairman*

MINES COMMITTEE

To the Board of Directors:

During the past year the Mines Committee has arranged for two combined meetings of local sections of the A. I. E. E. and the A. I. M. & M. E. One of these meetings was held in Pittsburgh on April 18th, at which time a paper was presented by Mr. J. C. Damon of the West Penn Power Company under the title of "The Use of Central Station Power in Coal Mines." A number of Bureau of Mines officials were present and the papers brought forth a lively discussion among coal operators and central station men present.

A second meeting was held in May in Chicago where two papers were presented; one by Mr. Clayton of the Illinois Central Power Company and the other by Mr. Adams, Electrical Engineer of Allen & Garcia, Consulting Engineers. Both papers were on the subject of "Central Station Power in Coal Mines;" one based on the viewpoint of the Central Station Company and the other from the viewpoint of the customer. During the coming year it is suggested that the Mines Committee encourage similar combined meetings in other localities.

Owing to the large stocks of metal and the quiet condition of most all of the industries during the past year, both metal and coal mines have been operating at low outputs. A number of the metal mines are, however, taking active steps to get started again and with the gradual improvement in industrial conditions, both metal and coal mines will enjoy an increase in demand that will be very gratifying. A large number of the coal mines are closed down at this time, due to a nation-wide strike. The large stocks of coal on hand together with the general slack condition of the industries, makes the effect of the strike little felt and unless the strike is soon settled the non-union fields will enjoy a very steady business.

Both metal and coal mines are contemplating extensive changes in application in electric power and in some cases active steps are being taken to place the mines in the best possible condition in respect to the use of power.

The use of central station power for mines is growing in popularity each year and it is now the exception for a mining company to install an isolated power plant if central station power is available. During the war the central station power systems were greatly overloaded resulting in poor service in many cases. Since the war the load has decreased and the central station systems have spent a great deal of time and money in strengthening their lines and improving their service so that very few complaints are now heard regarding poor service from central station power.

Improvements in the use of electric power in mines during the past year have been more or less curtailed and consist largely of improvements in loading machines, the further application of automatic substation equip-

ment and automatic control systems for mines, fans and pumps.

There has been little activity during the past year in regard to car dumpers, coal and ore bridges, shovels and drag lines, but there seems to be an indication of some activity during the coming year.

The by-product coke oven industry has been very quiet during the past year, but there seems to be indications that there will be considerable activity during the coming year. This will give the builders of by-product coke oven plants a chance to take advantage of some of the new schemes that have been recently developed and tried out.

GRAHAM BRIGHT, *Chairman*

MARINE COMMITTEE

To the Board of Directors:

The activities of your Committee have been somewhat affected due to the sudden and serious illness of the Chairman, Mr. Arthur Parker. However, we are pleased to report his gradual return to health.

Your Committee being associated with an industry, (shipbuilding), which received a great impetus during the war, finds itself in a somewhat similar position to that industry. The large fleets of merchant vessels tied up in all parts of the country and the question of disarmament has had a retarding effect on the program laid out by the Chairman at the beginning of the year.

Seven meetings have been held. The first, September 23rd, at which time the Committee was organized, Subcommittees appointed and the following work left from the previous year was undertaken:

1. Work of the Historical Committee.
2. Fixtures, fittings and etc. to meet requirements of the New Marine Rules.
3. Terminal facilities at piers.
4. Joint Meeting with the Society of Naval Architects and Marine Engineers for November 17th.
5. Adoption of Marine Rules by the American Engineering Standards Committee.

The following Subcommittees were appointed:

(a) To further the cause of having the Marine Rules adopted by the American Engineering Standards Committee.
(b) To write specifications for standard appliances.
(c) To detail power apparatus for auxiliary machinery.
(d) Propulsion Committee.
(e) Historical Committee.
(f). Radio Committee.
(g) Joint Meeting with Naval Architects and Marine Engineers.
(h) Wires and Cables.
(i) To have Steamboat Inspection Service include some requirement of electrical knowledge by licensed engineers and a separate electrical license for motorships.
(j) Editing Committee.

The year's work has been rewarded with many successes.

Through the efforts of Subcommittee (a), American Engineering Standards, the Institute is the sponsor body for "Electrical Installations on Shipboard," "Marine Rules." Thus, concluding the labors of our Subcommittee. President McClellan appointed our Subcommittee as an organization committee for the Institute to form the American Engineering Standards Committee and the work has progressed very satisfactorily and it is believed the Committee will be organized this Institute year.

Standard Appliance, Subcommittee (b), has completed specifications for feeder, junction and branch boxes:

Conduit and conduit fittings.
Fuses.
Receptacles, plugs, switches, non-watertight.
Receptacles, plugs, switches, watertight.
Bulkhead and conduit terminal tubes.
Steamtight fixtures and fittings.
Electric air heaters.

It is the intention to have these specifications incorporated in the reprint of the specifications and some arrangement made for the testing and approval of the appliances.

Power Apparatus Subcommittee (c), in addition to collecting data from the increased number of motor driven auxiliaries on shipboard and the advent of the motorship, where all auxiliaries are motor driven, making much data available, was assigned the duty of bringing the Marine Rules up to date so that when the American Engineering Standards Committee was formed, these suggested revisions would be available for their consideration, and this work has been concluded.

The Propulsion Subcommittee (d) has concluded the work assigned it, that of preparing "Recommendations for Protection of Electrical Apparatus for Use on Shipboard" and referred to in last year's report and it is the desire to have these Recommendations issued to all those vitally concerned. It is the opinion of your Committee that rules for propulsion machinery should not be prepared until a later date.

The Historical Subcommittee (e) has prepared considerable data bearing on electrical installation on shipboard from very early dates to the present and it is the intention during the coming year to prepare several articles giving the date, title, brief of the article and publication, also, supplement these articles with papers on electric propulsion.

The Radio Subcommittee (f) found that due to the rapid changes, it was thought advisable to revise that section of the Marine Rules. The Institute of Radio Engineers very gladly appointed a committee to assist our Subcommittee with this revision, which has been completed and we take this opportunity of thanking them. This revision will be available for the consideration of the American Engineering Standards Committee.

The Subcommittee (g) Joint Meeting with the Society of Naval Architects and Marine Engineers in New York, November 17th, desire special mention owing to the success attending this meeting. Two papers were read.

"Electric Auxiliaries on Merchant Ships" by E. D. Dickinson, Marine Department, General Electric Company and "Electric Propulsion" by W. E. Thau, Commercial Engineer, Westinghouse Electric & Manufacturing Company.

Both subjects were well presented. The discussions were numerous, long and heated and brought out many interesting facts, the most notable perhaps was in the discussion of Mr. Thau's paper that to date the electric drive had not shown as good economy as reduction gear drive, which was much to the surprise of a majority of those present.

Subcommittee (h), Wires and Cables, has been active in discussion of proposed changes, and, no doubt, the coming year will bring forth some desirable changes in the present specifications, as well as, uniformity in specifications for wires and cables for shipboard work.

Subcommittee (i), Steamboat Inspection Service, is of recent origin. The ever increasing use of electricity on shipboard, on steam driven vessels for economy, and on motorships from necessity suggests the necessity of the licensed engineer being familiar with the subject of electricity, which today is not a requirement for a license. The additional hazard can only be attended with diaster unless the personnel to whom the care of electrical apparatus is entrusted are required to have sufficient knowledge for its proper operation and maintenance.

Editing Subcommittee (j) has about concluded the work prepared by the Subcommittees (b), (c), (a), (f).

I desire to take this opportunity to thank each individual member and the Chairman of the Subcommittees in particular for their good attendance, enthusiasm and untiring effort, and congratulate them for the amount of good work done, particularly, in view of the absence of the Chairman and the lack of interest in the shipbuilding industry during the past year.

The coming year will bring many arduous duties, particularly, to the Subcommittee on Steamboat Inspection Service and it will only be by persistent and studious application that results will be obtained.

Acting for the Chairman, I will repeat the concluding paragraph of his 1920-1921 report:

"It is this thought in particular that I would leave with the Marine Committee for the ensuing year, that good work can only be accomplished through good will, consistant application and real cooperation."

G. A. Pierce, Jr., *Chairman pro tem*

IRON AND STEEL INDUSTRY COMMITTEE

To the Board of Directors:

Reversing Mill Drive Equipment

At present, economic conditions are such that an expansion of steel mills to produce a greater tonnage of steel is not important, and reversing mill electrification consists mainly in revamping present plants. This is either done by installing an electric reversing mill equipment in place of a steam engine, or it may be that the mill itself is obsolete, and the mill with its drive is replaced with electric drive and a new mill. This is usually done in order to replace worn out machinery, or to obtain advantage of lower cost of production. In the last two years, considerable attention has been given to the cost of producing steel and the reversing mill drive has received as much attention as any other type of mill. Considerable cost data are being published from time to time on electrically driven mills, so that it is a simple matter for those who are considering the installation of an electric reversing equipment to determine their cost with a very great degree of accuracy. This is something that has not been available heretofore, due to the difficulty in actually determining the amount of steam an engine takes. Several reversing engine installations have recently been made on the basis of obtaining some very substantial improvements in economy, but no results have been published from their installations, so that it is only natural to infer that the results which they had anticipated have not materialized.

In 1907, the first installation of an electric reversing mill was made in this country. Since 1913, the growth of the electrically driven reversing mill has been rapid, until today there are approximately forty installations in operation rolling all kinds of products. Although there are many features of this equipment which are still retained, the improvements in the design of reversing mill equipments have taken place so rapidly that our present day equipments have an entirely different appearance from those first installed. With each new installation, manufacturers have endeavored to incorporate features which permit the apparatus to perform its duty with greater ease, and thereby reduce the attendance and maintenance. Today, the majority of the electric reversing mill drives, regardless of manufacture, require very little attention, and the delays upon the mill are almost negligible. Attention over the week-end is seldom more than an inspection, which requires the service of one man for only a few hours. This is in quite a contrast to that required in reversing mill engines, including those which have been installed in the last few years. The art of applying electric drive on reversing mills has now reached a point where the capacity and characteristics of each machine involved can be determined very

definitely, and assurance given that the cost of attendance and maintenance is almost a negligible item in the total cost of producing steel.

A most important fact was the replacement of a twin tandem reversing engine which drove the first finishing stand, a rail mill, by reversing motor equipment. This equipment was the *first main roll electric reversing drive sold in this country to replace an engine.* It was sold in 1917, and delivered in 1918, but conditions at the user's plant were such as to make it inexpedient to install this equipment until this year.

The motor unit has the *highest continuous* horse power capacity (8000 h. p. 50 deg. cent.) of any electric reversing drive in the world. It was designed to roll the first four of the last five passes on a 105-lb. rail section at the rate of 240 gross tons per hour. The last pass is made in an adjacent mill driven by a separate engine. Although the equipment has not been fully loaded as yet, the mill has rolled at the rate of 198 gross tons per hour of 105-lb. rail, which exceeds all previous tonnage records on this mill. A particularly interesting feature is that this rate of rolling was made with the last finishing stand disconnected from its engine, and connected to the first finishing stand so that the motor was driving both stands and rolling five instead of four passes.

Owing to the depression in the steel industry no new tonnage records were made last year.

There has been some controversy as to whether the motor should be shunt or compound-wound. Both types of motors are giving entire satisfaction, from both a tonnage and maintenance point of view. The motors are built very strong mechanically, on account of the great shock to which they are subjected, and are provided with forced ventilation, as the natural ventilation of such machines would be extremely poor.

This equipment has been developed to such an extent that today it is practically standard, and installations can be made, and mills started in operation at their maximum capacity without any question as to the electrical equipment. In spite of the claims that have been made by some engine manufacturers, the economy of such equipments is so much superior to the engine driven mills that during the last six or eight years almost all reversing mills have been motor driven, and in the rehabilitation of older plants where engineering questions are given proper considerations the electric drive is the only type seriously considered. The ability of the electrically driven mill to turn out tonnage is beyond question, and in certain mills where the time element is of vital importance in providing tonnage, the figures obtained on machines driven by engines have been very materially improved upon.

Yard Electrification

Several of the largest steel plants of this country have under consideration, the electrification of their railroad yards, and considerable study has been given this subject with a view toward settling some fundamentals such as the selection between straight locomotives, storage battery locomotives, or a combination locomotive, using just sufficient battery to operate when a contact system cannot be continuous throughout the yard. The merits of each type of locomotive depend to some extent on the particular plant under consideration, but from a purely economical standpoint, the straight electric locomotive has a considerable advantage over the others. It is true in the case of straight electric locomotives that contact systems such as the overhead trolley line or the third rail conductor, have certain objections in a more or less congested yard with complicated track layout, but there are certain advantages which may or may not outweigh these objections. For instance, full time operation is possible since there is no tying up the locomotives to charge or change batteries, consequently for a given amount of work, fewer units are required; there is no periodic replacing of batteries; and rough usage of the locomotive such as it is very likely to get in steel plant yard service will not result in failure of battery, jars, etc. On the other hand, a locomotive which carries its own source of power has a primary advantage over any locomotive which must collect its power as it moves along. The storage battery has reached a high state of development in the mining industry, and there seems to be no good reason why the mine type of locomotive cannot be enlarged to fill the needs of the steel plant. Part of higher cost of operation over the straight electric machines can be compensated for by charging the batteries during off-peak load periods. The principal disadvantages of a storage battery locomotive, are the high first cost and renewal cost of the batteries, and to a lesser degree, the loss of energy which occurs in the battery.

It seems to be the opinion that third rail construction is preferable to an overhead contact system, due to the interference of any overhead wires or structures with the use of locomotive cranes, which are quite a necessary adjunct to the steel plant. Of the two designs, under-running and top contact for third rail construction, the former seems to be preferable because it is somewhat easier to protect with guards and occupies less space.

The standard direct current voltage for practically all large plants is 250 volts, and it would seem advisable to operate the yard locomotives on this circuit provided generating or converting apparatus can be so located that transmission losses are not excessive. In the event that heavy loads must be handled to a considerable distance from any substation, it has been pointed out that double voltage (500) could be used, and either the motor equipment on the locomotive connected for series operation, or 500-volt motors used which would operate at reduced speed in the 250-volt zone.

For railway work it will be necessary to ground one side of the plant distributing system, and some opera-

ting engineers will undoubtedly object to this, but the fact remains that systems are operating successfully with one side grounded. Return feeders on the grounded side will be required in most cases to prevent electrolysis.

Owing to the dull business period during the past year or more, finances have not been available for undertaking electrification work on a very large scale, but it is the present policy to start electrifying small portions of the yard and gradually adding to these portions until eventually electric operation will have been thoroughly tried out and the whole system will be changed over.

Main Roll Motors

In spite of the general depression from which our industrial interests are slowly but surely beginning to emerge, and in spite of the fact that the steel industry throughout the country has reached a point of low production wholly without precedent, a review of the large motors and auxiliary equipment purchased and installed during the twelve months period ending June, 1922, for driving rolling mills makes a very creditable showing. All motors purchased for main roll drives with the exception of those for reversing blooming mills are included in this analysis, whether for use in production of ferrous or non-ferrous metals. The application for rolling non-ferrous materials did not exceed 7.4 per cent of the total, and is but approximately 1.75 per cent for brass and copper.

Three of the large manufacturers of this type of equipment report a sale of sixty-four units with an aggregate normal rating of 97,590 horse power. It is a regrettable fact that the general adoption of a uniform method of rating proceeds so slowly. The Association of Iron & Steel Electrical Engineers has adopted the maximum continuous rating with 50 deg. cent rise in an ambient temperature of 40 deg. cent with a maximum momentary torque guarantee, but with no guarantee of sustained overload capacity.

Sixteen of the above motors aggregating 27,620 horse power were purchased on this basis.

Fifteen more aggregating 28,900 horse power were purchased on the so-called Steel Mill Rating under a guarantee to carry rated load continuously with 35 deg. cent. rise in an ambient temperature of 40 deg. cent. 125 per cent load continuously with 50 deg. cent. and 150 per cent load for one hour with 60 deg. cent. rise.

The remainder, thirty-three, aggregating 41,070 h. p. were purchased on basis of continuous operation at rated load with 40 deg. cent. rise in an ambient temperature of 25 deg. cent. and 125 per cent load for two hours with 55 deg. cent. rise.

This multiplicity of ratings is confusing and every effort should be made toward the universal use of a uniform standard method of rating as, for example, the maximum continuous 50 deg. cent. basis officially adopted by the A. I. S. E. E.

The types of mills electrified during the period under consideration include:

8 motors for Rod Mills	12,070 horse power
3 motors for Bar Mills	4,900 " "
14 motors for Merchant Mills	12,400 " "
4 motors for Cold Mills	1,950 " "
3 motors for Continuous *Sheet Bar and Billet Mills*	14,700 " "
15 motors for Hot Strip Mills	27,720 " "
1 motor for Structural Mill	4,000 " "
1 motor for Plate Mill	4,000 " "
2 motors for Hoop Mills	4,000 " "
2 motors for Sheet Mills	4,000 " "
3 motors for Tin Plate Mills	3,000 " "
1 motor for Tube Mill	1,600 " "
7 motors for Copper and Brass Mills	3,250 " "
Total 64 motors ... Total	97,590 horse power

It is interesting to note that five of these motors aggregating 15,600 horse power have been installed to replace steam engines.

The tendency toward higher speed with resultant lower first costs, improved power factor and efficiency continues. The successful operation of a 5000 h. p. 450-rev. per min. motor appears to have justified the design and construction of a 5750 h. p. 500-rev. per min. motor included in the above list for driving a Morgan Continuous Sheet Bar and Billet Mill. This is the largest capacity mill motor thus far built for this high speed.

The desirability of adjustable speed drives is still in evidence from the fact that 21 of the units listed, aggregating 35,370 horse power, have provision for adjustable speed control.

Thirteen of these units aggregating 26,970 horse power are of the well-known double range modification of the Scheribius system using an independent high-speed regulating set. This auxiliary set consists of a polyphase commutating machine and a squirrel-cage induction motor which receives the output of the main motor secondary at slip frequency and returns it to the supply system at line frequency. It also impresses on the secondary of the main motor a counter e. m. f. and frequency corresponding to the desired speed of the main motor.

Seven adjustable speed units, aggregating 7400 horse power for two mills, are ordinary direct current machines with shunt field control supplied from synchronous motor-generator sets. This reversion to an earlier type of adjustable speed drive in these two mills was determined largely by the greater simplicity of the direct current motor with shunt field control as compared with the a-c. adjustable speed sets, in spite of the lower over-all efficiency of the former.

Two adjustable speed units aggregating 1000 horse power are of particular interest as they embody some very recent developments. The main driving unit in this case consists of a mill type induction motor with a direct-connected synchronous machine on a common base.

The auxiliary machine consists of a frequency con-

verter driven by a synchronous motor. In the operation of the equipment, no torque is developed by the frequency converter and the driving motor supplies the power for windage and friction of the auxiliary set. In the operation and during regulation, the secondary of the main induction motor is connected to the commutator of the frequency converter and the slip-rings of the frequency converter are connected to the synchronous machine connected to the mill. This machine has the property when driven at synchronous speed, of taking the frequency impressed on the commutator and adding to or subtracting from the line frequency which in this case is the secondary frequency of the induction motor. The voltage delivered at the commutator end of the frequency converter is the same voltage as that impressed on the slip-ring end and as supplied from the synchronous motor. The synchronous machine on the main set and the synchronous driving motor for the frequency converter are excited with direct current.

After starting the main motor in the regular way as an induction motor, the secondary circuit is transferred to the frequency converter. This is done with no field on the synchronous machine and with the frequency converter running at synchronous speed. If it is desired to use a speed other than the normal, the rheostat, in the synchronous machine field is manipulated, putting a field on this machine. This causes the synchronous machine to generate a certain voltage which is transmitted through the frequency converter and impressed on the secondary of the main induction motor. This voltage, according to whether it opposes or helps the generated secondary voltage, causes the set to slow down or speed up. Any speed within the speed range can be obtained by simply adjusting the above mentioned field rheostat giving the desired practical range of speed above and below normal or induction motor speed.

Central Station Power

The use of central station power in the iron and steel industry, stands today as follows: Most of the major steel plants have their own power generating equipment, but quite a number of the large works with coke ovens and blast furnaces as a part of the plant, are using a central station connection and buying a small portion of the electrical energy required by the plant. This condition was brought about in some instances due to the fact that during the war, the power requirements in the mills increased faster than it was possible to secure and install additional generating capacity to take care of same, and it was found expedient to buy sufficient power to take care of these requirements. In other instances a lack of finances, or a higher rate of return on an investment in plant equipment other than power generating apparatus was the reason for central station power coming into the plant, but in all cases where there is a central station connection, it has been found to be a very great asset when a breakdown or trouble occurs in the local plant power houses, and as a matter of fact, it is an additional insurance against a total shut-down of the plant.

In some localities the question of frequency has kept central station power out of the plant. The central station generates 60-cycle power, but many steel plants use 25-cycle power for the reason that the motor equipment for large low-speed mill drives is better adapted for operation on this frequency, and until recently converting apparatus, for securing d-c. power which is essential for operating the mill auxiliaries was not as satisfactory on 60-cycle as on 25-cycle operation. In such localities, the use of central station power would require frequency converters or the changing of the mill equipment to accommodate the higher frequency.

Recent studies and reports on super-power systems have pointed out the advantages to be gained from a conservation and economical standpoint by interconnection, and the large steel plants with central station connections are a step ahead of the others in the super-power plans; however, there is one point to which the central stations which burn fuel to generate power, must sooner or later agree, and that is that they cannot always sell power over this connection, but in the interests of conservation and better mutual relations they should in return purchase some power from the steel plant, when this power can be generated from a by-product which would otherwise go to waste, such as is the case over week-ends when the coke ovens and blast furnaces must maintain uninterrupted operation, while a greater part of the remainder of the plant and the mills are shut down.

Now as regards the smaller steel plants where by-product energy is not available for the generation of power, it is almost invariably the case when these plants are located in some large central station power zone that they purchase the major portion of their power requirements. It is this type of plant that has demonstrated the fact that the steel mills can be operated just as well on 60 cycles as on 25 cycles, and that the central station power is found to be very reliable.

The steel mill engineer has two objections to central station power; its cost, and the hazard of a long line connecting his plant with the source of power supply. Under the first objection, he says that the restrictions or price penalties, under the present complicated rate schedules, when applied to his load, the nature of which is highly fluctuating with moderately low power factor, puts central station power out of discussion. On the other hand the central station power solicitor claims (and that very justly in most cases) that the steel man does not accurately figure his power plant costs, forgetting to take into account the fixed charges against the investment in his plant. However, in the final accurate analysis, it will be usually found that central station power cannot compete in prices with steel plant power, when the latter is all generated from the plant

by-products. Under the second objection; the length, type of construction, and territory over which the line is built, carry most consideration in determining the hazard. In plants where duplicate feeders over separate routes and into separate substations can be obtained, the hazard is reduced to a very low point, but in most cases this is not obtainable and it is advisable to have some reserve generating capacity sufficient to handle the vital plant load, such as pumps and hot metal handling apparatus in the event of a line disturbance or service interruption.

The Electric Furnace

Since its inception about forty years ago, the progress of development of the electric furnace has been one of unusual activity, especially the decade 1909 to 1919.

From the date of the first commercial electric steel furnace in this country, April 5th, 1906, with a capacity of four tons, the growth in number and capacity has been continually upward, so that in Januray 1st, 1922, there were 388 electric furnaces in the United States, and 50 in Canada. In maximum capacity this was reached in 1921, when two forty-ton electrics were placed in operation at the U. S. Naval Ordnance Plant at S. Charleston, W. Va.

These furnaces are basis lined and have a transformer capacity of 3300 kv-a. One furnace operates with 24-in. diam. amorphous carbon electrodes, the other with 14-in. diam. graphite electrodes, this giving current densities of 46.8 and 137.5 amperes per sq. inch respectively with the transformers at their maximum output of 21,000 amperes per phase. The relative electrode consumption on intermittent operation is approximately 20 lb. of carbon and 10 lb. of graphite per ton of steel.

During December of 1921, an order was placed by the Ford Motor Company for a 60-ton electric furnace for their River Rouge plant. This furnace will have six 24-in. diam. carbon electrodes and transformer capacity of 9000 kv-a. The year 1921, while not productive of much growth numerically, will be notable principally for the development of large capacities.

After the first development of the induction furnace, which came ahead of the arc furnace, it seemed to be overshadowed by the latter, as prior to 1914 the largest unit of the induction type in the United States was two tons capacity. The inherent low power factor of the furnace and the difficulty of maintaining a satisfactory refractory lining were greatly responsible for this lack of development. In 1914 two induction furnaces of 20-tons capacity were installed, but have not been entirely successful. Special applications of a 2-ton induction furnace have been made in the last two years, and a lining developed which, at last report, has withstood 555 heats. This is exceptional performance. It would be a great mistake to surmise that the retarded progress during the past year foretells any slowing down in electric furnace development. Indeed, it rather lays emphasis on how far and how fast the art has advanced.

Electric Cranes

The electric cranes used about the up-to-date steel plant represents as much development and as many changes compared with those in plants of twenty years ago as have been made in almost any steel plant equipment. When one considers the cranes of many years ago driven by a square shaft, running the entire length of the building; or a little later, equipped with a single motor and the various motions manipulated through clutches, with the modern steel mill four-girder ladel crane, equipped with the latest electric motors and apparatus, double-bridge drive, sturdy cast steel or structural steel construction, bronze bushed quickly replaceable bearings in place of the old style with babbitt poured in place, and equipped with the various safety devices, it is hard to realize they belong to the same family.

Dynamic braking and the use of additional electric brakes has supplanted, to a very large degree, the troublesome mechanical load brake. Accessibility and interchangeability of parts, the elimination of overhung gears, substitution of either bars or angles for the old style copper span wires, the use of automatic control for motors of, say, 35 h.p. and above, and the development of a control whereby additional speed may be obtained in lowering, and also, a magnified effort towards standardization are among the developments made in recent years.

During the last five years (the last one and a half due to the extreme depression, and the three and one-half years prior to that, to the war and after effects), there has probably been less actual development in connection with electric cranes than there were during the five years prior to that time. The last year has seen very few notable installations made. One of the largest and best known crane builders reporting, "There has been little of importance brought out within the last year or so, but we are working on several propositions that probably, eventually, will be of considerable interest."

The Association of Iron and Steel Electrical Engineers is working on a crane standard which will undoubtedly be recognized as a standard specification throughout the country, for heavy duty cranes.

Control Equipment

A most important development in magnetic control equipment has been perfected and put on the market during 1921. The design of contractors now makes it possible to obtain a steel mill controller with contacts and arc chutes having such life that it needs no longer be the regular week-end duty of the repair man to renew these parts on the severe service applications. Some plants have experienced the life of such parts to be as much as fifteen to twenty times that of former design. The newer design of contactor has several radical departures from the older type, in that all parts as far as

possible are made of punchings, being light in weight and very uniform, instead of castings which are heavier and require considerable machining. The result is a quicker operating switch of greater reliability. These contactors have been combined into standardized lines of magnetic controllers, utilizing the voltage drop relay scheme of current limit acceleration. Some of the advantages resulting from the use of the voltage drop relay system of control may be enumerated as follows:

The voltage drop accelerating system provides a combination of current limit and time element which allows the current limit setting to be high enough to provide torque for the heaviest loads and yet when the load is light and requires less starting torque, the time element will reduce the current and torque peaks to lower values. This prevents unnecessary punishment of motor and machinery during the light load periods.

The torque and current peaks during acceleration are, therefore, more nearly a function of the load than with any other system of acceleration. This feature is particularly desirable for applications requiring variable starting torque, such as steel mill auxiliaries. The time element is obtained by purely electric and magnetic means. No dash pots or mechanical devices are used.

Power House Equipment

In reviewing data submitted by various committeemen, the Chairman feels that this subject is one to be taken care of by the Power stations Committee, in that the developments in the power Stations located in the iron and steel industry, are identical with those of power stations in general, except that in a steel plant operating blast furnaces, the gas engine is used to great extent in place of the steam turbine on account of its higher thermal efficiency and greater flexibility in choice of unit size.

Electric Heating

Considering general industrial conditions, the use of industrial heating in the iron and steel industry has made a very satisfactory advance in the last year. The number of installations made shows that the industry is beginning to realize that, while electricity is essentially a high cost fuel, the actual cost of obtaining a desired result may be less when this high cost fuel is employed than when some cheaper heating agent, as gas or coal, is used.

Consideration has been given in one or two cases to the possibilities of electrically heated soaking pits. Several large steel plants have given consideration to the metallic resistor type of furnace for low-temperature heat treatment. In general, however, the possibilities of the metallic resistor type of furnace for work up to a temperature of 2000 deg. F. have not been followed up by the iron and steel industries to the same extent as has been increasingly noticeable in industries manufacturing steel products. This furnace is being used in the annealing of automobile castings and of locomotive parts, such as crank shafts, etc.

Arc Welding

While, in general, there have been no radical changes in arc welding processes employed in steel mills within the past year, there are indications that welding will be advantageously used in an increasing number of applications in this great industry. Undoubtedly, with but little attention and study, there could be found many new applications in which arc welding could be successfully and economically employed, especially since continued research has revealed new and more desirable methods of metal deposition, as well as new metals and alloys for use in repairing different materials.

It is well known that the repair of worn wobblers, one of the oldest applications of electric welding in steel mills, was formerly accomplished by the carbon arc process used primarily because metal could be rapidly deposited. This process is gradually being replaced by the metallic arc, with which ¼, ⅜ x ½ inch diameter electrodes are used, with current values varying from 300 to 800 amperes. The use of large electrodes and heavy current values is similar to the carbon arc process in that rapid deposition of metal is accomplished, but the use of the metallic arc has the advantage over the carbon process in that a less skillful operator is required to produce reliable welds.

A departure from the more or less standardized practise of using ordinary iron electrodes for building up of worn wobblers and spindles, is that of the use of high carbon steel, recently undertaken with success by different steel companies. There have been instances where old files have actually been used as the steel for the repair of worn wobblers, and when the supply of files was exhausted, electrodes were obtained having practically the same chemical composition. In all cases, the metallic arc was used in the process of repairing.

Aside from the more or less standard welding applications such as the repair of driving spindles, pinions, chipped and worn rolls, etc., the electric arc can be used extensively in the repair of all kinds of machinery in service in a steel mill. Until actually tried, the saving effected by repairing worn or broken machinery by the electric arc, cannot be fully appreciated.

E. S. Jeffries, *Chairman*

Preliminary steps have been taken for the introducing of radio broadcasting in Brazil and indications point to a promising future market for receiving apparatus. Until recently radio broadcasting was practically unknown, but the Centennial Celebration being held at Rio de Janeiro has served to stimulate interest in radio and various concerns in Brazil have been active in taking it up.

The requirements of the Brazilian law make it obligatory for any persons wishing to install a receiving set to secure a special permit from the Department of Transportation and Public Works. Only such receiving sets as have been approved may be sold by importers especially licensed to make such sales.

Discussion at Chicago Convention

CONTINUED DISCUSSION OF "MAGNETIC FLUX DISTRIBUTION IN TRANSFORMERS" (Mc Eachron). Chicago, Ill., April 19, 1922. See October Journal, page 757.

Alfred Still: In order to avoid the confusion of ideas which is likely to arise when the various components of the total flux are represented as occupying the same portion of the iron core, the vector diagram for a loaded transformer may be drawn as in Fig. 1.

Owing to magnetic leakage, the flux will not be the same at all sections of the iron core, and it is not possible to represent correctly the flux conditions in the transformer without abandoning the idea of each unit line or tube of induction being closed upon itself. In the sketch of the simple transformer shown in Fig. 1, the lines marked Φ_l represent the leakage flux while Φ_p and Φ_s stand for the fluxes which link with the primary and secondary windings respectively. The arrow-points indicate what will be considered the positive direction of these fluxes. It is then always true that the flux Φ_p is equal to the (vectorial) addition of the fluxes Φ_s and Φ_l, or,

$$\Phi_p = \Phi_s + \Phi_l$$

On the assumption that the magnetizing component of the current is negligible and that the winding ratio is 1 to 1, the vector diagram may be constructed as follows:

Draw $O\ E_s$ and $O\ I_s$ to represent the (known) secondary terminal voltage and current with the angle θ between them corresponding to a load power factor of cos θ. The other vectors are drawn in the following order:

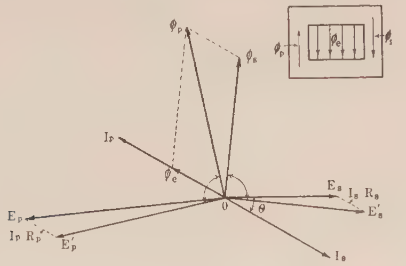

Fig. 1

$E_s\ E_s'$, parallel to $O\ I_s$ and of the proper length to represent the ohmic drop of $I_s\ R_s$ volts in the secondary windings.

$O\ E_s'$, the e. m. f. which must be induced in the secondary windings.

$O\ \Phi_s$, drawn 90 deg. in advance of E_s', is the flux which links with the secondary windings.

$O\ I_p$, equal and opposite to I_s, is the primary current.

$O\ \Phi_l$, in phase with I_p is the leakage flux.

$O\ \Phi_p$, the resultant obtained by the vectorial addition of Φ_s and Φ_l is the flux which links with the primary windings.

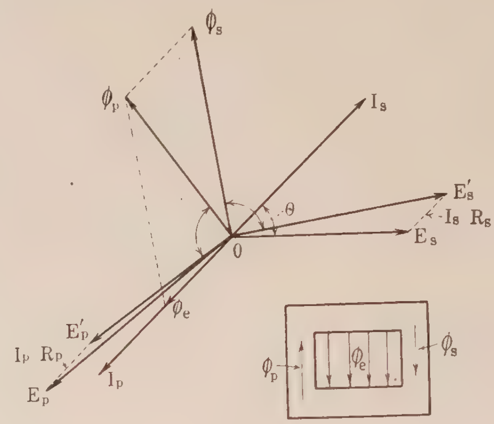

Fig. 2

$O\ E_p'$, drawn 90 deg. in advance of Φ_p, is the component of the impressed primary e. m. f. necessary to balance the e. m. f. induced in the primary windings by the flux Φ_p.

$E_p'\ E_p$, parallel to I_p and of the proper length to represent to ohmic drop of $I_p\ R_p$ volts in the primary windings.

$O\ E_p$, the voltage which must be impressed at primary terminals to produce the secondary load conditions which have been assumed.

In Fig. 2, exactly the same procedure has been followed in drawing the vector diagram for a transformer with a capacity load.

Discussion at Annual Convention

THE ECONOMICS OF D-C. RAILWAY DISTRIBUTION WITH PARTICULAR REFERENCE TO THE AUTOMATIC SUBSTATION*

(Crecelius and Phillips), Niagara Falls, Ontario, June 27, 1922

V. E. Thelin: The manually operated substations now in operation on railway systems in large cities offer a wonderful field for the use of automatic equipment, due to the fact that the line losses can be reduced considerably, schedule speeds increased, and in many cases sufficient copper can be taken down to pay for the cost of the land and new buildings as well as that of moving the machines. If the manually operated substations, which have a capacity of from 4000 to 20,000 kw., are redistributed into any number of single-unit or, at the most, two-unit automatically controlled substations, the service rendered by same no doubt will be far superior to that now obtained in the manually operated substations, due to the fact that each operation in the automatic substation has been worked out beforehand and the entire sequence is carried through without any hesitancy or error such as frequently happens to the operator in manually controlled stations. In the large manually operated substations with many units it is necessary to clear the board of practically all the feeder sections before the first rotary can be connected to the bus, whereas a single-unit automatic substation will have a maximum of say from five to eight feeders, and there should be no difficulty experienced in the station picking up all the sections simultaneously. It is possible, through the use of special devices which I have in mind, to isolate each substation district from all other districts, and by using automatic reclosing circuit breakers service can be restored quickly, whereas if all substations were tied together through bus lines the first station to be connected to the system would open up an overload through excess of load fed from the surrounding substation districts through the bus lines.

It seems, for many reasons, that the ideal automatic substation layout in a large metropolitan city is the single-unit substation layout. A two-unit substation requires the use of high-tension line oil switches, rotary oil switches and transfer switches, together with the expensive bus bar compartment construction for line busses, transfer busses and rotary busses, and where compound rotaries are used equalizer busses must be used, and the automatic control for a multiple-unit substation becomes very

*A. I. E. E. Journal, 1922, Vol. XLI, May, p. 363.

complicated, due to the fact that arrangements must be made for one rotary to carry the load in the light portions of the day and for additional rotaries to be brought into service as the load increases. Also, if trouble is experienced in the operation of one rotary, the automatic equipment must be so arranged as to cut in one or more rotaries, and the remaining rotary or rotaries are therefore called upon to carry the load which was originally carried by all of the rotaries originally in service in the station, which fact results in the remaining rotary or rotaries, as the case may be, being subject to an overload. On the other hand a single-unit substation can be constructed very economically, due to the fact that it is necessary to put in one oil switch only, which acts both as line and rotary switch, and which eliminates practically all of the expensive high-tension bus bar construction. By using one rotary, only, in the substation it is possible to put a 1000, a 2000, or even a 4000 kw. rotary in a building of simple construction on a 25-ft. lot. In case an oil cooled transformer is used, it is not necessary to build a basement in the substation, the cables being run in ducts under the floor and the rotary being set on a foundation with a pit in same, in order to get under the rotary for necessary repairs, etc. If air blast transformers are used, such as is now the case in a great many of the present hand-operated railway substations, the oil switch and transformers can be placed over a small basement-like compartment, which compartment would only have to be big enough for a man to enter to make the necessary repairs. The blower for cooling purposes is connected directly to this basement.

Fig. 1—Hammond, Whiting and East Chicago Ry. Co. System

I do not agree with the authors of the paper in their statement that a 3000 kw. unit is the minimum size which can be economically installed in city service, as I feel that with single-unit substations and simplified type of automatic control equipment it is possible to economically install substations with as low as 1000 kw. capacity.

The following figures might be of interest in connection with the application of automatic substations in city service. Fig. 1, shows the present layout of the Hammond, Whiting & East Chicago Ry. system. This system, which operates approximately 30 miles of track, originally was fed from one manually operated substation located in Hammond, which station contained four 400-kw. rotaries. In order to improve operating conditions, one of these rotaries was moved to East Chicago and equipped with various protective devices, which prevent any damage occurring in case of trouble arising due to hot bearings, over-speed, reverse current, etc. The feeders and the rotary are protected by means of automatic reclosing circuit breakers. The station is started in the morning by an inspector and left to run by itself all day, being shut down at night by means of a clock, which first trips out the circuit breaker and then opens the oil switch. This substation has been in operation as a semi-automatic station for approximately four and one half years, and has given very satisfactory results in normal operation. Shortly after this station was put in service another station was built at the north end of the system, viz. at Robertsdale. The power supplied to these three substations is furnished, however, from the same high-tension line, and after any interruption on this line it was necessary to carry the load on the two rotaries in the manually operated substation in Hammond until the inspector was able to get over and start the East Chicago substation, after which the Robertsdale substation was started. Having had some experience as a substation operator, I felt that a simplified automatic substation control equipment, with fewer parts than had been used heretofore in any automatic substation, could be developed, which would do electrically exactly what an operator does manually when starting a substation. After various tests and experiments such an equipment was developed, and has been in daily operation for approximately two years, having given very satisfactory results.

Fig. 2 shows the details of the automatic control panel in this station, as follows:

Directly below the time clock which starts the operation of the station is a master relay which energizes the various circuits in the station. Below that is a polarized relay, which determines whether or not the balance of the operation should be carried through or whether the polarity of the rotary should be corrected in case it came up wrong. Beneath the polarized relay is a combination field control and change-over switch, which, in addition to changing the connection of the field from the station bus to the rotary itself, also performs various other operations either simultaneously or with a certain time relay. The various protective devices shown at the top of the panel protect the rotary from all possible cases of trouble that may arise, such as

Fig. 2—Automatic Control Panel

reverse phase, phase failure, reverse current, over-speed, etc. The switches at the bottom of the panel are used for the purpose of cutting out the automatic equipment and reconnecting the balance of the equipment in such a way as to enable the substation

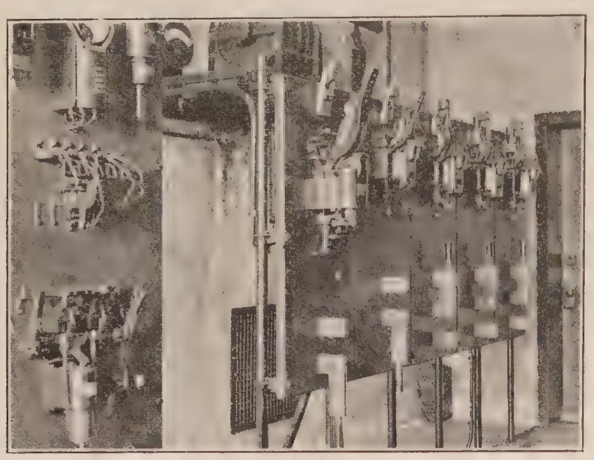

Fig. 3

to be operated as a semi-automatic in case any of the various automatic devices are out of order.

Fig. 3, shows, reading from left to right, the automatic reclosing circuit breakers on the rotary converter, the auxiliary bus and three feeders, respectively. The feeder breakers are

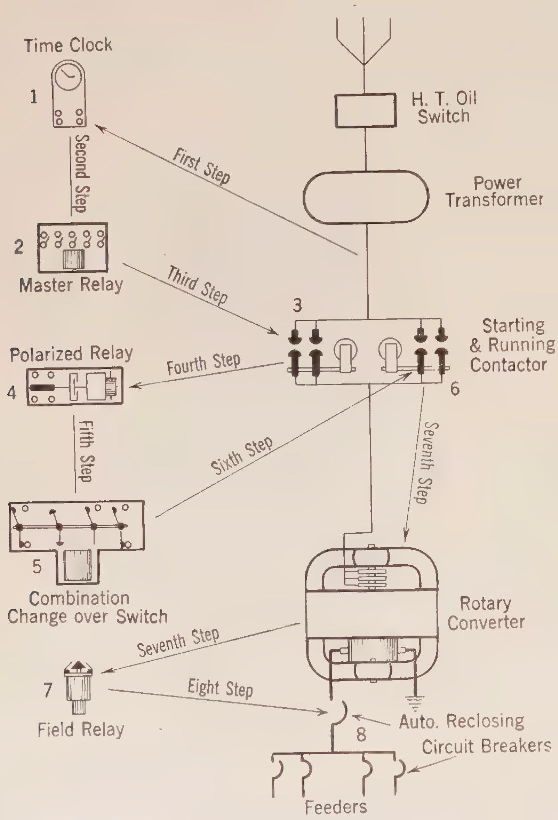

Fig. 4—Sequence of Operation of Automatic Equipment

bus sectionalizing breakers which are capable of being operated either with the station in operation or shut down, *i. e.* with power fed from the station bus or with back feed from some other substation through the bus tie feeders.

Fig. 4, shows the sequence of operation of the automatic equipment as follows: (1) Contact making time clock 1 operates. (2) Closing master control relay 2, which in turn (3) Closes starting contactor 3, which starts rotary. (4) Magneto-motor driven polarized relay 4, then operates, (5) Closing combination feed control and automatic change-over switch 5, which in turn (6) Opens starting contactor 3 and closes running contactor 6, (7) After which field-circuit time-limit relay 7 closes and, (8) Automatic reclosing circuit breaker 8 on machine panel closes, picking up station load. All of which operations require approximately 25 seconds.

In case the station comes up with reversed polarity, polarized relay 4 shuts the stations down, after which the rotary starts again and operations 1, 2 and 3, shown above, are repeated until the rotary comes up positive, after which the regular sequence of operation is carried through. This condition, however, will rarely occur, due to the fact that the field of the rotary is excited with one-tenth full strength field from the station bus during the time that the rotary converter is being started up, which causes the field to come up with correct polarity. Out of approximately 500 tests that were made with the field connected to the bus in this manner, there was only one case noted where the rotary converter came up negative, which possibly might have been caused by poor contact of some of the fingers, etc.

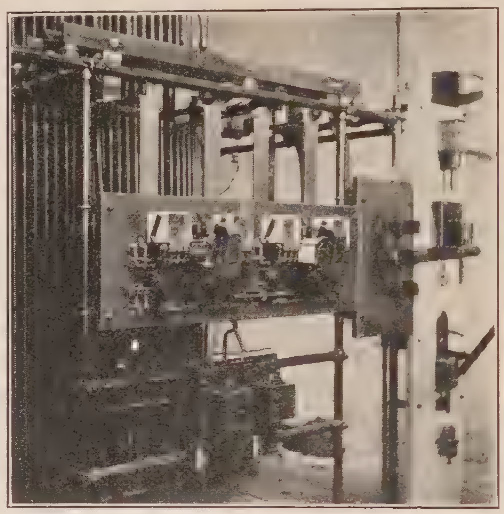

Fig. 5

The equipment is so designed that each operation in the sequence is a function of the one preceding it, *i. e.* each operation must be carried through successfully before the next one can take place. It is also so designed that if the d-c. automatic reclosing machine circuit breaker does not close and pick up the station load within a certain predetermined time after master relay 2 has closed, the self-correcting relay shown to the left of the time clock will then trip out the master relay, which in turn shuts down the rotary. The rotary then starts up again and if the trouble was caused by an imperfect contact or the sticking of some interlock, it may operate perfectly now and the entire sequence of operation is carried through, and the station load is picked up.

Fig. 5, shows, reading from left to right, the starting and running contactors for the automatic equipment; the manually operated starting and running switch; and, at the extreme right, the a-c. oil switch control panel.

The only other equipment in the station that is not shown in any of the accompanying photographs is that of the rotary converter, which I did not consider it was worth while to show, inasmuch as it does not show any new equipment.

D. W. Roper: The authors of this paper have brought out one point which cannot be emphasized too much, and that is

that if the introduction of the automatic station for railway distribution will provide a method of increasing the number of feeding points for the railway system, the electrolysis problem will largely disappear. The tendency has been to put in substations as large as possible so as to reduce the operating expense, that is, the expense of the substation operators, and that has served to make the feeding distances very long. With the automatic substation the tendency is in the other direction, to make the substations comparatively small, and in this way greatly increase the number of feeding points. As the length of the feeders diminishes very rapidly with the increase in the number of substations, so also does the length which the railway return current travels the rails reduce in the same way: and not only does this affect a reduction in the voltage drop in the railway return circuit, but also effects a material reduction in the losses in the return circuit.

If the operators of the railway systems in planning the rehabilitation which they are looking forward to, after the long period of depression—would install as many substations as economically possible, and in this way reduce their feeding distances, it will very materially reduce the complaints and the damage which have heretofore been caused by electrolysis.

W. E. Bryan: The subject of economics of railway distribution, especially in view of the advent of the automatic substation, merits the most careful study by the electric railway engineer. The economic side of this question has been too often neglected in the past, due in large measure to the fact that railway systems have grown through the process of consolidation and ideal distribution layouts were, therefore, difficult of attainment. The automatic substation has interjected an important element into the field and railway engineers must be prepared to take full advantage of this new development which means some readjustment of our previous ideas as to size of stations, type of buildings, etc.

As the writer has pointed out previously, variation in local conditions makes general conclusions applicable to cities of a given size not only difficult of determination, but of doubtful value as well. Not only must conditions in any particular city be studied as a problem by itself, but a solution applicable to one section of a city may not be the best solution for another section, due to variation in the cost of land, availability of conduit, etc. Another point which has an important bearing is the question of power supply. In St. Louis, for instance, the railways receive power from three sources, namely, purchased water power at 55 per cent load factor; purchased steam power at 40 per cent load factor and power generated in its own plants at 14 per cent load factor. St. Louis has several d-c. feeders which are admittedly poorly designed from a distribution standpoint, but which, nevertheless, considering the different costs of the various sources of power, provide the best arrangement from an economic standpoint.

The authors on page 363 derive a figure for the cost of distribution amounting to $250,000 per year which they state is fairly representative of cities of the size of Cleveland. As the figures in this tabulation are used more or less throughout the paper, the writer has drawn up comparable figures for St. Louis which indicate that the annual cost of distribution in that city amounts to approximately $505,000 per year. It should be stated that the investment data used is based on conservative valuation figures recently prepared for presentation in a case before the State Public Service Commission, and corrected as of April, 1922. Incidentally, it might be brought out at this point that the larger the distribution loss, the greater the possible saving which can be effected by the use of an increased number of substations. In other words, if as the authors conclude, stations of 3000-kw. capacity are best adapted for cities where the annual distribution cost is $250,000 per year, it seems logical that if the distribution loss is considerably in excess of this figure a greater number of stations and, therefore, stations of smaller capacity are justified.

In view of the wide difference in the annual costs of distributions just referred to, a brief explanation of how the writer's figure of $505,000 was obtained is in order. The carrying charges on feeder investment are found to be $135,000 as compared with the figure of $130,000 used in the paper. The writer's figure represents a 10 per cent charge on a valuation of $1,350,000 for positive and negative distribution circuits. In view of the low depreciation of copper the writer considers 10 per cent preferable to the 13 per cent fixed charge rate used by the authors.

The principal variation, however, comes in the second item, namely, the carrying charges on that portion of the investment in generating plant, transmission lines and substation equipment necessary for supplying the peak load distribution losses. The writer's figure is $240,000 as compared with the figure $92,000 derived in the paper. This difference is due to two factors; first, an increase in the cost of investment per kilowatt of direct-current demand from $165 to $258: second, the distribution losses during the peak, based on many readings taken at various points scattered throughout the city, was found to be for St. Louis practically 15 per cent as compared with 10 per cent as used in the paper.

Returning to the first item just mentioned, namely, the investment per kw. in generating plant, transmission lines and substation equipment, it is important to bear in mind that this figure is based on the d-c. demand at the substation bus. With a coincident half-hour average d-c. demand of 45,000 kw. (the figure for St. Louis), the demand at the generating bus amounts to 53,000 kw., the average loss at the time of peak load for transmission and conversion amounting to 15 per cent. If it is assumed that the generating plant should have a reserve capacity of 25 per cent and that its present day cost would amount to $125 per kw. of capacity (which is considered by the writer a very conservative figure), the investment cost in generating plant reduced to the basis of d-c. demand amounts to $183 per kw. The addition for transmission cable, underground conduit and substations brings the total to $258 per kw. It would seem that the figure used by the authors, namely, $165, is considerably lower than could be realized in practise, especially in view of the statement at the bottom of page 367 of the paper, that generating plant investment alone might be as high as $150 per kw.

This factor, that is, fixed charges on investment necessary to supply peak load losses, is the most important of the three factors entering into distribution costs and if automatic stations, especially in congested districts are properly adjusted as to voltage, a very material saving in the item will result due to the saving in distribution losses.

For the third item entering into the cost of distribution, namely, operating expenses of generating plant, transmission lines and substations necessary to supply distribution losses, the writer obtains $130,000 per year as compared with $28,000 given in the paper. Although the same "Loss Factor" is used, the writer has applied it to the peak load loss, multiplying the resulting figure by 8760, and not to the annual kw-hr. output, as was inadvertantly done by the authors. The difference is further increased by the use of 15 per cent distribution loss on the peak instead of 10 per cent, and to a slightly higher energy charge for power.

A comparison is given on pages 374 and 375 of the use of stations of various sizes ranging from 1500 to 6000 kw. Messrs. Crecelius and Phillips have determined the probable distribution distance for each of the stations considered and have worked the problem out on this basis. The railway engineer is usually confronted with the necessity of taking care of a given district and the question to be determined is whether the district shall be fed by one, two or perhaps more stations. This would seem to be, therefore, the more logical basis of comparison, and in his

comments on the conclusions presented in the paper the writer will give actual figures derived from the downtown section of St. Louis. In passing, however, it might be pointed out that the investment costs of the 3000-kw. station and the two 1500-kw. stations used by the authors are $43 and $53 per kw. respectively. A comparison of a 2000-kw., two-unit station and two 1000-kw. stations for St. Louis resulted in investment costs of $38.25 per kw. for the former and $39.75 per kw. for the latter. These figures are based on the actual purchase price of equipment recently bought by the United Railways and estimated costs for land and buildings, these latter, however, being obtained from figures for land actually purchased for substation sites and buildings recently built for two automatic substations now in service. In explanation it might be pointed out that the cost of the control equipment for the two-unit station is, as might be expected, slightly higher than the cost at the two single-unit stations, due to the additional control devices necessary in a two-unit station. This difference is more than offset, however, by the increased cost of land and buildings for the single-unit stations, but as we have been able in St. Louis to secure inexpensive land (rear portions of lots, etc.) and erect simple and inexpensive buildings, these factors are not of great importance. The writer wishes to stress the point, however, that the maximum advantage of automatic stations can only be obtained where land and building costs are held to a minimum. Automatic equipment lends itself to simple and inexpensive types of buildings.

In the operating costs derived by the authors for 3000-kw. and 1500-kw. stations, the larger station is given a material advantage in efficiency. This point will be covered later, but it is evident that if the efficiencies were practically the same there would be little advantage from an economic standpoint in favor of the 3000-kw. station. What advantage remains would be more than offset by increased freedom from electrolysis and greater reliability, advantages which are brought out in the paper.

Commenting on paragraph (b) of the conclusions (page 376), the writer cannot agree that, "in cities . . . the economic advantages of the automatic substation are relatively small, because distribution cost is a correspondingly small part of total cost." As shown previously, distribution costs are a material item in the cost of supplying power to a railway and the automatic station undoubtedly has a large field in urban work. Further study and experience is necessary before the question of its relative value for interurban, as compared with urban service, can be definitely answered.

In paragraph (c) the authors conclude that in view of the lower efficiency which they say is to be expected with automatic stations, some plan of remote control will probably be found advisable, so that converters can be operated at or near their best efficiency. This conclusion evidently is based on the efficiency curves of 60-cycle converters which constitute a minor portion of the converters in use on railway systems. Efficiency curves of the 25-cycle converters differ from those of 60-cycle converters in two important respects. First, very little increase in efficiency is obtained as the size of the unit is increased above 1000 kw.; and second, the variation in efficiency from three-quarters to one and one-fourth load in the case of 25-cycle units is about ¼ of one per cent. These figures are based on the combined efficiency of converter and transformers. Manifestly, it is of comparatively little importance at what point the unit is operated, provided it is above three-quarters load. Even at half load the efficiency of a 25-cycle 1000-kw. converter and transformer is only ¾ of one per cent, less than its maximum. The curves on page 370 of the paper giving the efficiencies of 60-cycle units at various loads show that the efficiency of a 1000-kw. unit at 50 per cent is 2½ per cent rating less than its efficiency at full-load rating.

In St. Louis the five new automatic stations recently purchased are laid out to carry approximately 125 per cent of rating for the maximum half hour which would result in an average load of about two-thirds of rating. The relays will be set so that the stations will run practically continuously for sixteen to eighteen hours per day, the slight loss in station efficiency at the lighter loads being more than offset by the saving in distribution losses. The stations and feeders are so designed that if one station is out of service the overload on adjacent stations will not reach the danger point, nor will the distribution voltage be seriously affected. It should be remembered that such equipment is capable of 50 per cent overload for two hours and, furthermore, the stations being small and comparatively close together, prolonged overload at any one station is very unlikely.

In connection with the conclusion set forth in paragraph (d), namely, "in such cities as Cleveland, it is doubtful if the capacity of substations can be profitably reduced below 3000 kw., . . .," the writer cites the following: In St. Louis it was desired to reduce the load on a 12,000-kw. substation feeding principally the heart of the downtown section. It was decided to move two 2000-kw. interpole rotaries from their locations in existing stations into the downtown district fed by the 12,000-kw. station. Three alternatives for the use of this equipment presented themselves. First, a single 4000-kw. station manually operated; second, a single 4000-kw. station automatically operated, and third, two 2000-kw. stations automatically operated, spaced approximately 4500 ft. apart. Without going into detail, (the writer will be glad to furnish the detailed figures upon request) the following figures represent the annual costs, based on the investment necessary for *additional* equipment, and land, buildings, transmission cables, distribution cables, together with allowance for distribution losses: 4000-kw. station manually operated, $14,250; 4000-kw. station automatically operated, $13,800; 2-2000-kw. stations automatically operated, $13,000. In view of these figures, together with the greater freedom from electrolysis and increased reliability, it was decided to adopt the plan involving two 2000-kw. stations automatically controlled, and equipment has been purchased and land for these stations acquired. Each station is supplied by two transmission cables.

In view of the figures just given the writer feels that for cities similar to St. Louis, the 3000-kw. station is not the minimum size justifiable. Furthermore, if automatic stations of 2000 kw. can be justified in a congested downtown district, where the feeding distances are comparatively short, it seems evident that in districts outside of the downtown area, where conditions more nearly approach interurban conditions, the automatic station of smaller size, say 1000 kw., finds a useful field. It is not contended that in areas like the loop district of Chicago, where concentration of load is extremely heavy, that automatically controlled equipment will be found advisable.

The conclusion expressed in paragraph (e) that if possible, standard size of unit and standard control layout be used in all stations, is open to the objection that if units of one size are used exclusively, the maximum distribution economics cannot be obtained. Division between various sizes, of course, should not be carried to too fine a point, but it would seem that for a city the size of St. Louis, 1000-kw. units would be best for general use, with 2000-kw. units for the downtown district and other points of heavy load concentration, and say 500-kw. units for use at outlying points and on interurban lines. Such a plan will not, it is believed, materially increase the necessary stock of spare parts, since many items of the control equipment are the same for various size units.

Relative to adopting a standard control layout, while this plan has material advantages, it also has certain commercial disadvantages and, furthermore, it should be borne in mind that we can expect to see changes of a more or less radical nature in automatic control equipment as the art develops.

M. J. Lowenberg: In the design of a distribution system, whether it is for a small railway system or a heavy electrification, it is necessary to determine the permissible voltage drop.

Often, especially today when capital costs have to be kept down, irrespective of any economy that theory may show according to Kelvin's law, that value is the minimum value to operate the trains or cars.

A very simple law is that for the most economic layout the cross section at any point should be proportional to the square root of the current at that point.

I have found from computations checked by tests, that whether it is a single car or a long train, or a number of cars or a number of trains, that a very accurate method is to assume that this current at any point (to which the cross section is proportionate to its square root), is the maximum starting current of any single unit—(which in a street railway would be a car and in a subway would be a train)—plus the current due to average load uniformly distributed along the line.

In using Kelvin's law great care must be taken not to throw an undue burden upon the stockholders. Kelvin's law is subject to a tremendous variation, without changing the economy derived from theory. As a matter of fact, 35 per cent less copper than shown by Kelvin's law would in theory give approximately only 10 per cent increase in annual cost, and if you put the question to a banker he would tell you to leave out the 35 per cent copper.

Another point in the paper which is not entirely in agreement with practise is the variation of the size of cables. In most systems, especially large systems, there is more or less standardization—especially on underground work. There you must standardize on a certain sized cable, irrespective of what your theory shows. These things will often upset Kelvin's law, to which too much weight must not be given.

The extent of spare equipment, whether feeders, substations or rotaries, must be determined in co-operation with the transportation department; for then only can you determine the value of service and therefore the amount of relay equipment which has to be installed.

E. R. Shepard: The paper is of particular interest to me because of its possible bearing on the question of electrolysis. If, through, the use of semi-automatic or remotely controlled substations, the feeding capacity at any one point in a city system can economically be reduced to from 1500 to 3000 kw. we may find in such systems a final and satisfactory solution for this baffling problem. That such will be the case is by no means a foregone conclusion as the establishment of numerous substations throughout a city will create new positive conditions on the underground structures which in some soils may prove injurious.

The application of insulated negative feeders for the mitigation of electrolysis, while improving the general conditions, have in a number of instances created new positive areas with consequent damage to pipes and cables.

Where relatively few and large generating or supply stations are in use they are frequently located outside of the congested or highly developed sections of cities, and in such cases electrolysis conditions are often either endured or taken care of by local treatment. With the use of frequent automatic substations, some would usually be located in congested areas where the underground utilities are not only of great value but where the interruption of service or the failure of water pressure cannot be threatened.

The use of additional supply points for power distribution is, of course, in the right direction to eliminate electrolysis, and I am not unmindful of the great benefits which may be derived from carrying such a system to the economic limit. It is not evident, however, to what extent such a system will remove the cause of electrolysis and the railways may well assume that they will have this problem with them until direct current has been supplanted by some other form of motive power.

L. P. Crecelius and V. B. Phillips: Mr. Thelin has said "I do not agree with the authors of the paper in their statement that a 3000-kw. unit is the minimum size which can be economically installed in city service, as I feel that with single-unit substations and simplified type of automatic control equipment it is possible to economically install substations with as low as 1000-kw. capacity."

The authors agree with Mr. Thelin that some simplified form of control may justify the installation of substations of less than 3000 kw. capacity. To correct any wrong impression that may have been created as to the opinions expressed by the authors, it may be well to quote from conclusion (d) of the paper. "In such cities as Cleveland, it is doubtful if the capacity of substations can be profitably reduced below 3000 kw. with the *control equipment now available for full automatic control*, commencing at the incoming supply line and extending throughout the entire substation operation" * * * * * "If, therefore, any *substantial saving* in the total cost of power is to be had by the smaller sizes of substations, automatically controlled, it will be necessary to reduce substation losses by improving methods of control" * * * * "There are, of course, some distinct advantages to be had by installing small capacity substations of say less than 3000 kw. These are principally the mitigation of electrolysis, and under certain conditions an increased factor of safety."

It would appear that Mr. Bryan has not correctly interpreted the mathematical procedure and examples upon which the authors have based their conclusions, with which conclusions Mr. Bryan is not altogether in accord. Mr. Bryan refers to the tabulation given on the first page of the paper as being "used more or less throughout the paper." It should perhaps be pointed out that this tabulation was given simply for the purpose of illustrating in a general way the magnitude of the several elements which go to make up the total cost of distribution. These figures are not used or referred to again in the body of the paper.

Mr. Bryan has preferred to use 10 per cent in arriving at the carrying charges on copper. This is, of course, a matter of opinion. The authors arrived at 13 per cent by using an 8 per cent return on the investment, which percentage has been quite generally allowed throughout the country by the state public utility commissions; 2½ per cent for taxes, which is the tax rate in Cleveland and which in view of steadily increasing tax rates throughout the country is not believed to be excessive; and 2½ per cent for depreciation. It is true that depreciation on the copper itself is very slight, but it must be remembered that the rate applied to the cable in place must take account of the rather rapid depreciation of insulation and cost of stringing. It is believed that in a comparative study of this kind, depreciation of feeder insulators and fixtures need not be included for the reason that this investment is practically the same for different sizes of feeder. If these items be included the result will not be substantially affected.

With regard to the amounts used by Mr. Bryan for generating plant, transmission line, and substation investment, it may be said that the unit values used will depend upon the basis of valuation. There is a wide difference of opinion among rate making bodies as to the weight that should be given to the high prices prevailing during the last few years, especially in appraising for rate making purposes such plants as were installed prior to 1915. On the basis of present day costs Mr. Bryan's figure of $258.00 per kw. is undoubtedly more nearly correct than the figure of $165.00 used by the authors. At the same time, the figure of $165.00 is quite consistent with the valuations used by a number of different public utility commissions in determining rates. The present tendency is toward the purchase of power from central stations by electric railway companies. On account of the diversity of load on these stations the investment properly allocable to a single consumer or class of consumers is substantially reduced. The demand charges for purchased power in the larger cities range from as low as $12.00 up to $27.00 per kw. of demand per year. The figures used on the first page for these carrying charges, viz: $23.00 per d-c. kw. of demand per year,

including carrying charges on substation investment and taking due account of the substation losses, is believed to be reasonably consistent with the demand charges mentioned above, as well as consistent with the valuations on power plants and transmission lines accepted by many rate making bodies.

In the opinion of the authors, Mr. Bryan's discussion of the paper presents figures and observations of no little interest and value. Mr. Bryan touches upon a number of points that must certainly receive due consideration in any study of the problem of distribution.

Mr. Lowenberg's statement that "Kelvin's law is subject to tremendous variation without changing the economy derived from theory" is, in the main, true. In other words, the cost curve is fairly flat on either side of the point of maximum economy. It must, however, be borne in mind that the load on feeders in most progressive American cities is continually growing, for which reason it may prove wise to install more than the minimum copper as contemplated by Mr. Lowenberg. The application of Kelvin's law in cities gives substantially more copper than is necessary to satisfactorily operate cars. On the other hand, in the case of interurban lines on which distribution distances are necessarily much greater, Kelvin's law will call for little, if any, more copper than will generally be necessary to obtain satisfactory car operation. The authors certainly did not contemplate such strict application of the law of economy as to depart from that "more or less standardization" of cable sizes to which Mr. Lowenberg refers. Very few theoretical engineering laws of this sort can be precisely applied in practise. Kelvin's law gives the theoretically proper sizes of cable corresponding to maximum economy in distribution. In other words, it affords a standard of performance to be approached as nearly as may be practicable, but which of necessity must be modified in many cases by reason of various practical considerations. Mr. Lowenberg points out that it may be difficult or unwise to invest more than the minimum of capital necessary to conduct transportation. This is, of course, a matter of financial policy rather than engineering computation. It is one of those practical limiting conditions referred to above.

Mr. Roper and Mr. Shepard have referred to the mitigation of the electrolysis difficulty by the installation of a larger number of distributing points. In their analysis, the authors have not specifically considered the savings that may result from the use of a large number of small substations in cutting down electrolysis damage claims or in reducing the necessity and cost of various mitigative measures. This omission must not be interpreted as indicating any lack of appreciation on the part of the authors as to the importance of this phase of the subject. It is scarcely possible, however, in an analysis of this kind to introduce the factor of electrolysis because of the tremendous variation in local conditions governing corrosion from stray currents. The examples worked out in the paper for a typical mile of track show a rather small variation in total cost for the several different substation sizes. It may frequently happen that a serious electrolysis situation will justify the use of smaller substations than would be dictated by the other purely economic factors.

In conclusion, the authors wish to say that their primary purpose in preparing this paper has been to set up a procedure for the study of the distribution problem in a comprehensive way. The various examples which have been worked out have been intended more for the purpose of illustrating the application of the principles involved than for the purpose of reaching any very definite conclusions. Railway substation control is still in process of development. There is a great variation in the many factors which go to determine the proper solution of the distribution problem in different localities. As previously pointed out, questions of financial and operating policy, including the importance attached to continuity of service and the resultant provisions that may be necessary to reduce the possibility of shut down, must be given consideration along with the theoretical economic factors. At the same time, it is believed that the starting point at least is a purely economic analysis along such lines as have been suggested in this paper.

QUESTIONS RELATING TO STANDARDS OF RATING* (Newury);

PROBABLE VALUES OF CONVENTIONAL ALLOWANCE FOR A-C. GENERATOR STATOR WINDINGS† (Newbury) TEMPERATURE LIMITS IN LARGE MACHINES‡ (Torchio);

Niagara Falls, Ontario, June 28, 1922

W. J. Foster: I agree closely with Mr. Newbury's conclusions and with his recommendations regarding the method of rating machines by temperature rise and also the figure that he has mentioned as the ultimate temperature rise of Class *B* insulation in the armature windings.

This paper of Mr. Newbury's on the Conventional Allowance is a fine example of laboratory work, but I consider it like all laboratory investigations, something that should be used with caution in applying the results.

There are differences in the way in which the temperature is attained in the different parts of the Laboratory Model that vary very widely from what exists in rotating electric machines. For example the temperatures of the iron are obtained by heat entirely from within the coils embedded in the slots, while in the ordinary machine, only about one-half of the heat is generated in the coils.

Now, in the case of the heat originating inside of the insulated coils, it is necessary to have the temperature attain a very much higher value in order to bring the core up to the temperatures that are carried through the investigation as shown in the tables ranging from something like 10 deg. to 70 deg., and consequently the embedded detector which lies in the line of the heat dissipation has quite a different temperature; in other words, the difference between the inside temperature of the coil and the embedded detector is in my opinion, greater than in the average rotating electric machine. Similarly, the variations that are taken to represent the different types of machine—long core, short core and the different potentials, I do not think should be taken as equivalent to test results on actual machines.

I speak of this, because I do not want it to be generally imagined or thought there will be a 15-deg. difference, between the measured temperature and what may exist inside.

In these investigations, concerning which I have a great deal of interest, having more or less charge of such investigations in our company, fully one-half of the machines referred to in Mr. Newbury's paper, the inside temperatures at the ratings of the machines, in many cases were no higher than those measured by the detector, indicating no drop whatever, which is not unreasonable. The fact is, we can conceive of a machine so designed that the temperatures in the inside of the insulated coils are no higher than at the spot where embedded detector is located outside the insulated coil.

Such machine would involve a broad slot, and thin insulation, and a very narrow temperature detector, and the machine very conservatively rated, with certain relations existing between the heat generated in the iron and that in the copper.

I was very much pleased with Mr. Torchio's paper, since it is a contribution along the lines that are very greatly needed. It is experience that should be taken as the basis of standardization. In my opinion, standardization should not anticipate too much the possible progress that may be made. We should know our ground well, before we standardize for the future. Standardization is largely a matter of present knowledge, based on past experience.

*A. I. E. E. Journal, 1922, Vol. XLI, July, p. 527.
†A. I. E. E. Journal, 1922, Vol. XLI, September, p. 636.
‡A. I. E. E. Journal, 1922, Vol. XLI, June, p. 446.

As I understand Mr. Torchio and Mr. Newbury, the 80 deg. allowable temperature rise is recommended, and I am in sympathy with basing the rating on temperature rise, rather than hot spot temperatures. As I understand it, this 80 deg. rise is to be considered good practise, but the upper limit of good practise.

R. F. Schuchardt: The great importance that attaches to this subject is due not only to the millions of dollars invested in these large units, but also to the fact that the reliability of the service, and also in large measure the safety of the system, are involved.

Mr. Torchio deserves the gratitude of the industry for the most heroic insistence and persistence with which he has fought for conservatism in this line, and I want to voice my accord with his position. As a result of his work this compromise of 80 deg. has been reached. From the very limited data that are available, this must of necessity be a compromise.

On the one hand, the maker naturally is optimistic over his own work, and perhaps he has more faith in the materials than the user would have, and feels that a higher temperature makes for greater progress. It is entirely natural he should feel that way. The engineer, who has these large systems to operate, on the other hand, believes that reliability is the first thing to be sought, and the very last thing to be given up. Because of their comparatively high economy, these large units must be as dependable as it is possible to make them. The economy is realized only when these units are in condition to be operated on the base load. The operating engineer, therefore, naturally does not take the same optimistic view of the situation as the manufacturer might. He must be conservative.

We have heard that some of our foreign colleagues feel that higher temperatures are advisable. Without data, that seems to us as accepting a shorter life, and particularly for the very large units with the long coils. It is not entirely a question of the temperature that the materials themselves will withstand, so much as the mechanical result of the expansion and contraction, due to these large ranges in temperatures.

I think the evidence of the failures in Mr. Torchio's machines indicate it is not the temperature itself that caused the breakdown, so much as the effect of expansion and contraction—the mechanical rubbing on the mica, and grinding it up.

In conclusion, the thing we should do first is to cooperate to get more data, but meanwhile the user, because of his responsibility for safety and for reliable service must be conservative.

W. F. Dawson: I think, with the gentleman who spoke before, that we are to be congratulated on this compromise, as we call it, because I know there are some members of the Institute who think the value is too low, and others who think it is too high. I personally think that they have decided on a splendid value for the rating of Class B insulation in stators.

There is one feature about the temperature of 100 deg. cent., which I do not think has been mentioned, although it may have been hinted at. Nothing has been said about the possibility of aging of armature steels at high temperatures. I have not had any personal experience with aging, but I do know from the experience of transformer designers that steels which are not alloyed, which are not the silicon steels, will not stand continuous operation at 150 deg. cent., without a large increase in the loss.

As I understand it, this happy compromise allows 80 deg. rise with the ambient temperature of not over 40 deg. That makes 120 deg., and when one adds the hot spot correction, of, say, 10 deg., gives total of 130 deg. That is high enough, but I believe it is not too high.

I think that Mr. Newbury recommends 100 deg. rise in field. That seems reasonable and I don't think we need go down to 80 deg. rise.

You can say that you want something reliable to be able to understand what the manufacturers are bidding on—yes, but you want something which is competitive too, to get the most in capacity, for the dollars you put into your investment. We do not want to fix any false standards we cannot live up to.

R. B. Williamson: I feel very much gratified to see that we are going back to the idea of specifying a straight temperature rise. Machines have been built for a great many years under a specification of 40 deg. cent. rise by thermometer for Class *A* insulation.

Now, in the case of Class *B* insulation on stators, we are considering 80 deg. rise, with the difference that instead of specifying it by thermometer we are specifying it by imbedded detector and omitting all temperature corrections. This simplifies the whole method of determining temperatures, and it is in effect simply going back to the former method except that the measurement is made in a different way.

Mr. Schuchardt has brought up an important point in connection with Mr. Torchio's paper. That is, it is not, whether 80 deg. or 90 deg. is safe for mica, because we know that mica in itself will stand higher temperatures than these, but it is a question as to the mechanical effects of the high temperature on insulation. It has been demonstrated by Mr. Torchio that high temperatures may affect the binder causing the insulation, in some cases to loosen to a certain extent; we then have the condition of loose conductors in a magnetic field, and these are bound to vibrate more or less and chafe the insulation, so that a breakdown finally results from the mechanical action rather than from the heat. In rotors, the insulation will stand these high temperatures without trouble, because the mica is held very firmly mechanically, and there is not the opportunity for vibration that exists in the stator. Also in the rotor the voltage is low whereas in the stator of large machines the voltage is usually high.

C. E. Skinner: Referring in Mr. Torchio's paper to Figs. 4, 5 and 8, the graphs showing the temperatures of these machines. Mr. Torchio states that the temperatures are either from copper measurements or are arrived at by a method giving the equivalent conventional allowance. Now, these particular machines 4 and 5, are older machines, and they have heavy, solid conductors, while the machine referred to in Fig. 8 has laminated conductors. It is very possible, therefore, that the differences in Figs. 4 and 5, as against Fig. 8 are greater than the figures given in Mr. Torchio's graph, for the reason that the eddy currents, particularly in the top conductor, are probably very much greater in the first two machines than in the later machines, and consequently the earlier machines have a greater hot spot temperature than the graph would indicate.

I think that may possibly account for the greater difficulty of the earlier machines.

F. W. Peek, Jr.: I do not believe that it is good engineering to use insulations at extreme temperatures. It is my opinion that the Sub-Committee has come to a fortunate conclusion in adopting this principle.

H. L. Wallau: In connection with Mr. Torchio's paper, there have been a certain number of experiences in Cleveland which may be of interest. The question raised by Mr. Torchio as to what limiting temperature shall be standardized for large turbo-generators is of vital importance to the central station industry, and requires thorough and painstaking investigation.

Mr. Torchio's curve, Fig. 1, showing the life curve of fibrous insulation based on the data obtained by three independent sets of investigators is very interesting, but is limited to the effect of temperature alone and cannot of course, show the combined effects of temperature, mechanical stress and ionization.

It is possible that the shape of this curve holds true for Class *B* insulation although by definition the "binder is used for structural purposes only, and may be destroyed without impairing the insulation or mechanical qualities of the insulation."

If this is strictly true the life curve for Class *B* insulation as affected by temperature alone, probably would be quite flat over a range of 150 deg. cent. in temperature.

Fig. 2 shows that the average air temperature in New York is much nearer 20 deg. than 40 deg. cent. with a maximum for the year of 32 deg. cent.

This is roughly typical of our lake cities, but is probably much

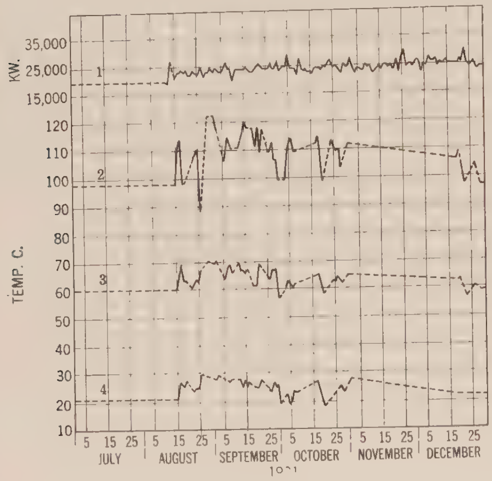

Fig. 1—Operating Log No. 8 Turbo-Generator, Lake Shore Station for 5 Months of 1921, 25,000 Kw., 11,431 Volts, 1800 Rev. per Min.

1. Daily Maximum Kw. Output
2. Daily Maximum Field Temperature
3. Daily Maximum Armature Coil Temperature
4. Daily Temperature of Intake to Air Washer-Field temperatures calculated from rotor resistance.

Dotted lines indicate no recorded readings.

lower than temperatures prevailing in the Mississippi Valley during the summer months.

It would therefore seem that the standard ambient reference temperature of 40 deg. cent. should be retained.

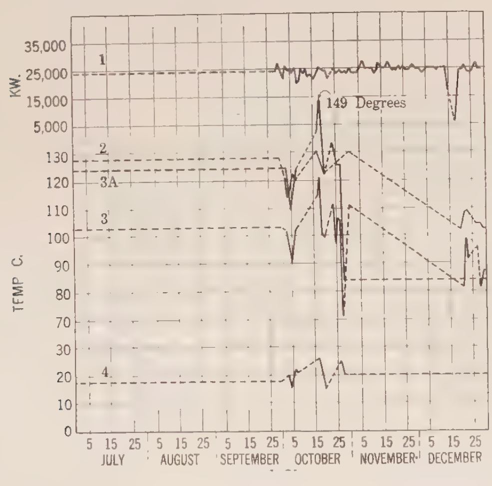

Fig. 2—Operating Log No. 9 Turbo-Generator, Lake Shore Station for 3 Months of 1921, 25,000 Kw., 11,430 Volts, 1800 Rev. per Min.

1. Daily Maximum Kw. Output
2. Daily Maximum Field Temperature
3. Daily Maximum Armature Coil Temperature

3A. Daily Maximum Calculated Temperature on 2½ Per Cent Increase per 1000 Volts

4. Daily Temperature of Intake to Air Washer

Dotted lines indicate no recorded readings.

Mr. Torchio's Figs. 4, 5 and 6 indicate conditions prevailing in his plant quite at variance with those obtaining in Cleveland. In general, no machines in Cleveland have been operated at armature temperatures of 145 deg. to 155 deg. cent. maximum.

The bulk of the Cleveland load is an alternating-current industrial supply, the power factor averaging about 80 per cent during the day.

This condition has resulted in making the field temperature the limiting factor and it is our practise to limit the field tempera-

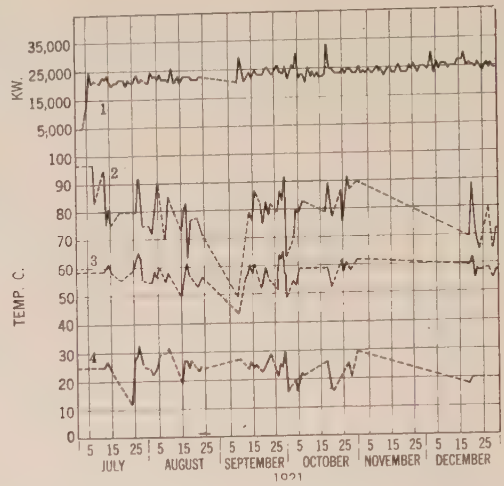

Fig. 3—Operating Log No. 10 Turbo-Generator, Lake Shore Station for 6 Months of 1921, 25,000 Kw., 11,431 Volts, 1800 Rev. per Min.

1. Maximum Daily Kw. Output
2. Maximum Daily Field Temperatures
3. Maximum Daily Copper Temperatures
4. Maximum Daily Temperature of Intake to Air Washer

Dotted lines indicate no recorded readings.

ture to 125 deg. cent. The operating temperature is determined by resistance measurement.

Armature temperatures as determined by imbedded coils or thermo-couples have generally not exceeded 70 deg. cent. except in the case of one unit. This unit has reached 122 deg. cent.

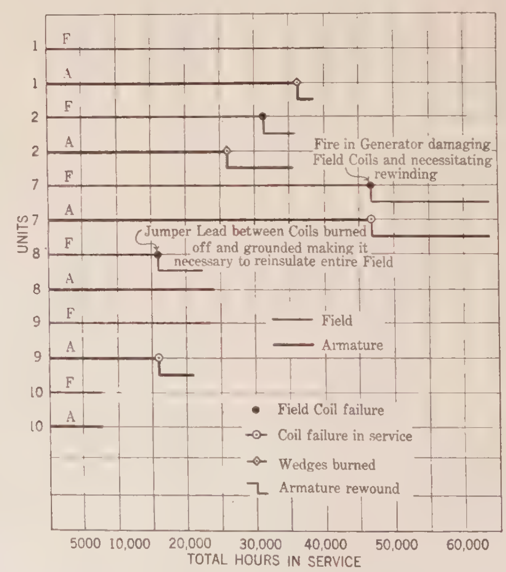

Fig. 4—Record of Generator Coil Failures

Hours out of service for rewinding armature and field are deducted from these given hours.

and making the correction suggested by Mr. Torchio of 2½ per cent increase per 1000 volts computed on the rise above air has reached the 149.2 deg. cent. (Manufacturer guarantees 150 deg. cent. safe operating temperature).

Charts Figs. 1, 2 and 3 for three units similar to Mr.

Torchio's Fig. 4 are appended. A chart Fig. 4 similar to Fig. 6 is given showing the performance of our horizontal units. In each case the upper line refers to the field and the lower to the armature.

It will be noted that we experienced field trouble on units No. 2, 7 and 8 and armature trouble on units No. 1, 2, 7 and 9.

The life without failure in years was

Unit No.	Field	Armature
1	—	4.17
2	3.59	3.03
7	5.42	5.42
8	1.82	—
9	—	1.82
10	—	—

(Dashes indicate no failure to date.)

The record of our vertical 14,000 and 15,000 kv-a., 1 power factor, 11,430-volt units is as follows:

Unit	Installed	Repairs	Date	Elapsed time
No. 3	Sept. 1911	Field reinsulated	July 1920	8.8 yrs.
" 4	Aug. 1911	" "	May 1918	6.7 "
" 5	Dec. 1912	No repairs		9.5 "
" 6	Oct. 1913	Grounded field repaired	May 1918	4.6 "

In the case of a third unit, this was suspected but could not be definitely established.

The fourth unit which failed ran hotter than the others from the beginning. In installing the armature coils it seems that the slots were filed to allow the windings to be inserted. It is our belief that the burrs resulting from this filing, caused severe local heating in the laminations. In the accompanying cuts, Figs. 6 to 12, the lightly shaded areas show the spots where the insulating varnish on the laminations had been completely destroyed.

Fig. 6—Armature Lamination Showing Portions Subjected to High Temperatures which Destroyed Insulating Varnish No. 9 Generator

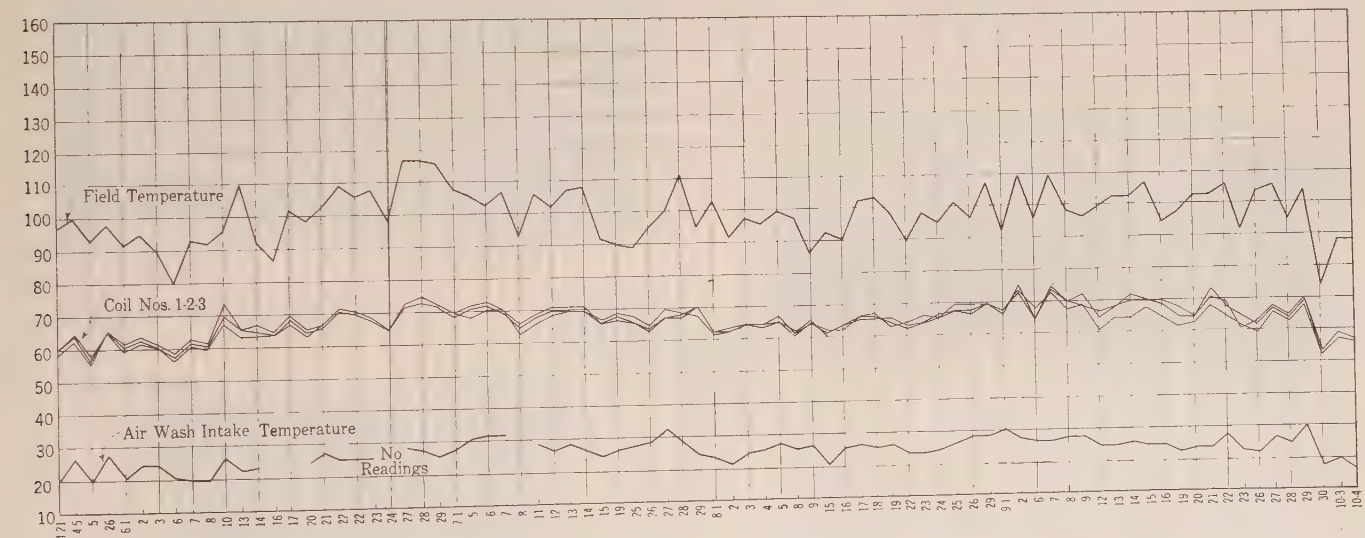

Fig. 5—Temperature Readings on No. 1 Turbo-Generator Lake Shore Station Starting April 4, 1921 to October 31, 1921

All of these units are in commission.

The maximum armature temperature (by thermometer) reached by any unit was 69 deg. cent., and the approximate average armature temperatures during the summer months have been 55, 58, 50 and 50 deg. cent. respectively since installation.

The maximum field temperatures (by resistance) reached were 93 deg. for the coolest field to 109 deg. cent. for the hottest field, that of No. 5 unit. For all that, this is the one unit on which no field trouble has occurred.

In practically all cases armature failures have been accompanied by more or less pulverization of the mica, indicative of mechanical pounding, often by bulges in the insulation, resulting in air pockets and consequent ionization.

The armature failures of two of our horizontal units were plainly the result of grounding of the corona shields in certain slots. On rewinding these shields were omitted.

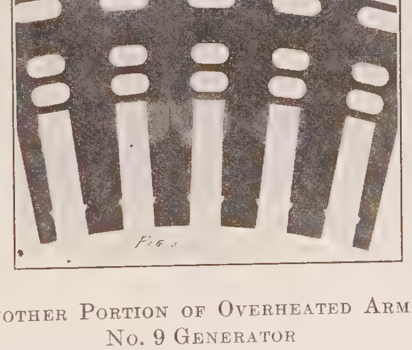

Fig. 7—Another Portion of Overheated Armature Core No. 9 Generator

It was necessary to install an entire set of new laminations as well as a complete armature winding.

Two other illustrations Figs. 13 and 14 show the condition

of various coils of No. 1 generator, in one a burned wedge shows very plainly. The bulges and powdered mica (white pots on coils) are readily discernible.

After this machine unit No. 9 had been rewound and placed in service one of the detectors indicated a coil temperature of 195 deg. cent. The field was withdrawn and the armature examined.

Fig. 8—A Portion of a Damaged Coil that Crossed Ten Air Ducts. Coil Bulged and Insulation Cracked at Edge of Ducts. No. 9 Generator.

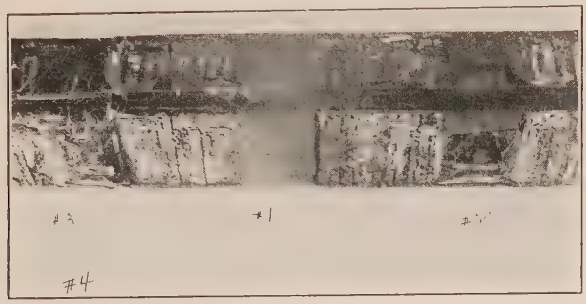

Fig. 9—Close Up of Fig. 3—Showing Bulges and Powdered Mica Insulation and Effect of Static. No. 9 Generator.

Fig. 10—Close Up of Other Side of Bulge No. 3 Shown in Fig. 4—No. 9 Generator

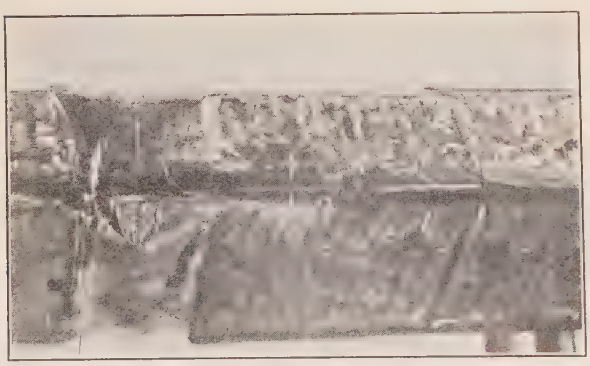

Fig. 11—Close Up of Another Bulge in a Damaged Coil. No. 9 Generator

A small hexagonal nut was discovered lying on top of one of the slots near the detector in question. When in operation the magnetic stresses had caused this nut to vibrate and peen the edges of the laminations considerably. This confirmed our belief that the original trouble was caused by the filing of the armature slots. (In the rewinding process the slots were lined up and after the coils had been inserted the bolt holes were filed where necessary for the proper insertion of the through bolts.)

After the nut was removed and the edges of the laminations ground and varnished, insofar as possible, the machine was again put in service.

Before carrying load, but operating at full speed and excitation, it was found that five of the detectors indicated an average temperature of about 78 deg. cent. while the sixth, still showed high, reaching 131 deg. after a 3½ hour run. Intake air 17 deg., exhaust air 29 deg., maximum rise 114 deg. cent.

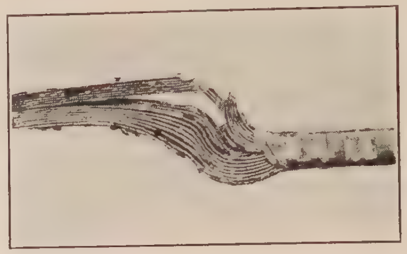

Fig. 12—The Section of Coil that Broke Down. The Bend in the Coil was Due to its Removal from the Slot. Note that the Break-Down was at the Air Duct. No. 9 Generator.

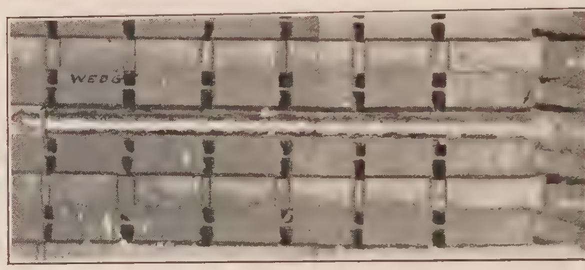

Fig. 13—Damaged Coil in Place. Note Burned Wedge at Left. Other Wedges were Either Partly Burned or Completely Destroyed. No. 1 Generator.

Fig. 14—Another Damaged Coil—Wedges Removed. No. 1 Generator

Under load this difference in temperature between different detector coils irons itself out and the maximum difference noted is about one-third as great as that and often less.

In conclusion, our experience as a whole indicates that our troubles have not been caused so much by temperature as by mechanical pounding and ionization.

Since the higher temperatures would aggravate these effects, we are in accord with Mr. Torchio that a limiting temperature of 125 deg., for standardization purposes is as high a value as should be adopted.

H. R. Woodrow: The manufacturers are greatly indebted to Mr. Torchio for bringing before the Institute in such concrete form the requirements and methods from the operating field, giving a definite idea of what they consider reliable and satisfactory service. Mr. Torchio is also responsible to a large extent for making it possible for men with different ideas to get together on temperature ratings. For instance, on conventional allowances opinions vary from 5 to 30 deg. In the larger machines of today, we know from experimental data what these allowances should be.

Another point which the Institute should clear up is the classification of Class *B* insulation. As Mr. Newbury brought out, there is still considerable uncertainty as to Class *B* insulation, and how much Class *A* material should be permitted in its construction.

The question of field insulation temperature limits as Mr. Williamson brought out should be definitely classified. There has been some trouble due to field insulation failures, and as the papers do not cover that point, would it not be possible to have it covered in this discussion.

H. G. Reist: I too wish to congratulate the Committee on getting back to the old standard of giving the rise instead of the more complicated expression for determining the temperature, which we have used for the last several years. It has been pointed out that since the French standard has been changed, and the American standard of a lower temperature has been adopted, that they have had better results than formerly with their machines.

A friend of mine, an engineer, who has been in France within the year, told me that in one installation of large American built induction motors that was made during the war, the owners expressed extreme delight in the service which they had obtained. They said they never had an experience such as they had with the use of these motors, because they have not had any trouble from burnouts. That is due to the fact that they were running at lower temperatures than the French motors.

Several speakers have expressed the opinion that 80 deg. rise for Class *B* insulation, which we all know usually has some organic material in its makeup, should be the limit.

I would like to ask the question, since the French engineers have followed our lead with good results, and we would like, as far as possible to lead the rest of the world in this industry, is it good policy for us to standarize to the limit?

This idea I am going to speak of has already been expressed in a different way, but it seems to me the question may be resolved into a mathematical equation, the same as the amount of material you can afford to put in a machine, or how much you can spend for the roof on your house,—Is it not a question whether the first cost, the cost of the loss in the machine, the repairs, and the lack of service of one temperature balance against similar results if you use some other temperature. Would not the solving of that equation give you the answer? It has been pointed out that generally high temperatures means greater loss and less efficiency, and we all agree that however good we make an insulation, for 80 deg. or any other temperature rise, it will be a little bit longer lived if we run at lower temperatures and therefore repairs will be less frequent and the expense of repairs and the loss from lack of service will be less.

James Lyman: I believe that we all heartily agree with the standardization that has been presented to us. The manufacturers of large turbo-generators have so improved and advanced the design of the machines, that as regards temperature they are able to build machines corresponding to these lower temperatures.

There is no part in the development of the industry of greater importance than the reliability of these big turbo-generators. We have read, within a few months, the report of the Super-Power Committee. More rapidly than most of us realize there will be in use throughout the length and breadth of this country, a universal 60-cycle power supply. It will be on the order of the outlines of the Super-Power Committee. On the Pacific Coast, in the Middle States, in the East, we shall soon have in operation 220-kv. power lines, transmitting power of the order of 100,000-kilowatts per circuit supplying cheap power, not only in our industrial centers but wherever industry wishes to locate in the country, and nothing can be of more vital importance to the success of these undertakings than the reliability of the large turbo-generator units which are the source of supply for these systems.

L. T. Robinson: It seems to me we have made a great gain in our method of procedure, by giving weight to the things which we know about, as opposed to starting from the end that we were least certain of, to arrive at the result. On the old plan we started with 125 or 150 deg., or whatever it was, and which we at that time were not at all certain of, and which we have subsequently become even more doubtful of, and we assumed a certain conventional allowance, and took that off, then we assumed an ambient temperature of the surrounding cooling medium, and took that off, choosing such values so that after we had taken them off, we would have the circuit temperature rise left.

Now, we have decided to start from the other end, and take what we know, and forget the other things. Therefore, it is unnecessary to discuss this matter of 15 or 20 or 30 deg., conventional allowance, as opposed to the present five, and propositions that have been made for 5 and 10. The way it looks to me is that all the figures, taken together, do not point to any change with sufficient definiteness so that the change should be made.

I am, therefore, very pleased to know that we can in the future be satisfied to rate machinery on temperature rise alone, and I am also pleased to endorse Mr. Newbury's proposition that all other subject matter that relates to how the temperature rise was arrived at, be taken out of the rules, and perhaps be put into an introduction that would show the mental processes we went through in order to arrive at the values chosen.

With regard to Mr. Torchio's figure of 80 deg., I join the others in complimenting him on having so steadfastly stood for a certain figure throughout all the time that the rest of us have gone back and forth, sometimes have advocated one thing, and sometimes another, but we have returned to the original figure of ten years ago, and the rules as they now stand are exactly in accordance with the proposition which has been advanced and agreed to, if the foot-note No. 2 to §1005 of the 1921 Rules which refers to the 150 deg. is crossed out.

I would like to say one word about the distinction that I think should be observed between rating and application, and if we can have that distinctly and clearly in mind, I think even the difficulties of some of our foreign associates can be removed.

We now rate machines on temperature rise, and therefore the temperature rise determines the kw. or kv-a. that is marked on the nameplate, the question of "ambient temperature of reference" does not come into the matter, I think that what we want are rules for marking a machine of definite size, and therefore definite capacity, with a certain rating, *i. e.*, a certain kilowatt capacity, and then we should clearly know that it is well within the province of the user, if he pleases, to make some allowance for the fact that conditions of use may not be exactly the conditions that were established as the basis of the rating.

There may be some questions as to what extent anything of that kind should be done, but clearly, if the situation is such that the surrounding temperature is more than 40 deg., we should hesitate to put as much load on the machines as the rating calls for. On the other hand, I think in the interest of conservatism we should—when the ambient temperature is lower than the 40 deg. which has been established—hold in reserve that capacity which must, to some extent, be there, for a reasonable margin of safety.

P. Torchio: In answer to the question of Mr. Foster, I confirm his understanding that the 80 deg. rise is to be considered good practise, but the upper limit of good practise. Mr. Skinner's comments on the copper temperatures of the machines Nos. 4 and 5 are correct, but perhaps the figures I have given may still represent the actual maximum temperatures because since the paper was printed I found that the assumed constant of $2\frac{1}{2}$ per cent increase per 1000 volts computed on the rise of the detector between coils is in fact excessive, a constant of about $1^2/_3$ per cent being closer to the average of result of several tests on machines especially equipped with exploring detectors in contact with the copper.

Mr. Wallau's valuable contribution fittingly supplements my paper. He, however, with some of the other speakers, emphasizes the importance of establishing a different standard for the temperature rise of the rotor windings. I am in full agreement with Mr. Dawson that a higher limit must be allowed for the rotor. From Mr. Wallau's presentation, a rise of 90 deg. would represent good and safe practise. I would endorse such a limit. It may be that the higher figure of 100 deg. suggested by Mr. Dawson may prove necessary for structural reasons. A little further study and cooperation should lead to an early agreement also on this point.

Referring to Mr. Wallau's and other speakers' comments on the life curve of fibrous insulation of Fig. 1, I do not know whether Class B insulation would have any similarity with the behavior of fibrous insulation. My reason for incorporating this Fig. 1 in the paper was not in an attempt to apply the results of fibrous insulation to Class B insulation. The only idea was that as in all windings we are always confronted with the presence of fibrous insulation either as binder of mica or in straight insulation of coils in the end turns, therefore, to cover fully the subject it was necessary to introduce the data given in Fig. 1. Incidentally, I call the attention of all engineers to the varied application that this fundamental information may have in all practical applications of the power industry.

F. D. Newbury: Mr. Foster questions the results obtained from the laboratory model described in my paper on Conventional Allowances, mainly because of the different manner in which heat is produced in the model, and in a generator. I do not see that this has any bearing on the conclusions reached. The problem was to establish the relations between certain temperatures inside and outside the insulation. To study the desired relations, a range of temperature values was produced. How this range of temperatures was produced was of no more consequence in this case than would have been the manner in which values of e. m. f. might be produced in a similar study of voltage drops in an electric circuit.

The particular values of temperature produced in this model were also of little significance so long as they covered a wide range. Thus, the fact, noted by Mr. Foster, that the difference between the copper temperature and core temperature in some of the experiments is greater than found in most generators is of no moment.

The model was used to establish certain temperature relations and a rational method of calculation for the conventional allowance. These relations and method were then checked by comparison with the results from generator tests. These generators were selected for test and tested under the supervision of Messrs. Foster, Williamson and the writer (each acting separately for generators manufactured by their respective companies.) Table IV, showing the comparison between calculated and tested values, is the criterion by which the work with the laboratory model should be judged. Considering the difficulties and errors inherent in machine temperature measurements, I believe Table IV shows a satisfactory degree of agreement.

Mr. Foster also points out that in fully one-half of the machines tested there was little difference between the inside temperature and the temperature measured between coils. This is true because these machines were of such dimensions (as to core length, insulation thickness, etc.) as to result in small temperature differences. Reference to Table IV will show that, in general, where the tested values are low, the calculated values are low also.

I do not believe that Mr. Foster has said anything that justifies any change in the conclusions reached as to probable values of conventional allowance, summarized in Fig. 10.

Mr. Torchio has used an empirical relation to calculate the conventional allowance that takes into account the single factor of rated voltage of the generator. The principal factors that determine the conventional allowance are the temperature difference between copper and outer coil surface, the temperature difference between top and bottom coil-sides (determined principally by eddy current factor) and the insulation thickness. In generators of less than 40-in. core length, the core length is also a factor. It is obvious that a relationship that neglects all but one of these factors can give reasonable results only if the other factors do not vary in generators of varying sizes, proportions and manufacturers.

This matter of conventional allowance has ceased to be of importance in specifying performance of machines, but is still of major importance in the work of standardizing committees in deducing allowable temperature rises from safe limiting temperatures of insulation. This, I hope, justifies this rather long discussion of what might be considered a purely academic question.

The agreement on 80 deg. as a satisfactory standard that has been expressed is very gratifying to all those interested in progress in this matter, and should make it possible for the Standards Committee to put this agreement in official form. The Standards Committee will, no doubt, also consider the question of rotor temperature limits. While this phase of the question has not received the same attention as has the armature winding temperature there has not been the same divergence of opinion and agreement should not be difficult.

Jean Canivet: In answer to Mr. H. G. Reist's remark concerning the satisfaction which was given in France by the American motors, I would like to emphasize the fact that the trouble we experienced with the French motors built according to our old rating was probably not due so much to the high temperature rise admitted than by the overload *without temperature limit* which was then allowed.

LIGHT WITHOUT GLARE*

(Harrison) Niagara Falls, Ontario, June 27, 1922

F. C. Caldwell: The lack of understanding on the part of the public of the whole problem of lighting was well brought out by Mr. Harrison's paper. One point needs a little more emphasis and that is the erroneous idea that glare is solely a function of brightness. Mr. Harrison has clearly demonstrated that the glare produced by excessive quantity of light is more serious than that produced by too great brightness. This is just one example of the general misapprehension of these simple laws on the part of even intelligent people.

H. Calvert: There is one statement, made in the first paragraph which may be correct, but does not appear to be so. I refer to the statement:—"they forget that the 200 candle power lamp of the present generates no more thermal units than did a single candle in the days of our forefathers." It would be interesting to know how this conclusion was reached.

G. H. Stickney: Glare in lighting represents an undesirable effect, which is readily recognized, but not so easily defined. In a general way there is more or less of an agreement as to what conditions of lighting constitute glare, but to express systemati-

*A. I. E. E. Journal, 1922, Vol. XLI, August, p. 609.

cally, the relative importance of brilliancy, contrast, flux, position etc. as contributing causes, has so far baffled the illuminating engineer.

He recognizes that there are degrees of glare, that the glare encountered in one place is worse than that met in another. It, therefore, follows that there should be some way of measuring glare.

A glareometer which would give a reasonable measure, would be a great boon to the lighting art. It would not only facilitate research, but also would assist greatly in the specification of good lighting, the writing of codes, and the inspection of any individual lighting installation.

A number of engineers have given quite a bit of study to this problem, and have made brilliancy meters, contrast meters and pupil meters, but none of these, so far as known to the writer, has proved sufficiently comprehensive or practically applicable to various conditions. While it is still to be hoped that a suitable instrument will be forthcoming, the necessity of the art is such that, some other method, of at least classifying conditions in terms of the relative degree of glare, is required. This method, described by the author, seems to present the most practical scheme that has yet been suggested.

The scheme is really comparatively simple. From observation and experience, the various ordinary illuminants are graded from I to X with regard to their glare reducing powers. Then with a similar symbol, the permissible degree of various operations are tabulated, with reference to the position of the illuminant in relation to the eyes of the subject workman. This provides a means of deciding that a selected illuminant does not exceed the limits.

Of course, this is empirical and perhaps arbitrary, but at least it is fairly definite. It appears to be reasonable and in line with experience. In case later experience should show that certain changes in classification should be made, it would seem practicable to make such changes. But in the interest of practical utility, the author's classification should be adhered to for the present. Having been incorporated in the Illuminating Engineering Society's Industrial Lighting Code, now an American Engineering Standard, the glare classification seems to be ready for useful service.

On the other hand, it is to be hoped that research, which may lead to an absolute instrument or method, may be continued, neither interfering with the other until a real improvement is brought out.

Ward Harrison: Mr. Calvert asks about the relative amount of heat generated by a candle and an incandescent lamp of 200 times its intensity. The comparison is about as follows:

An ordinary paraffin candle 13/16 inches in diameter burns down at the rate of 1¼ in. or a little less than 0.025 pounds per hour. The generally accepted B. t. u. value for hydrocarbons such as paraffin is from 18,000 to 22,000 B. t. u. per pound; $20{,}000 \times 0.025$ equals 500 B. t. u., the approximate heat units liberated by a candle in one hour.

A 150-watt Mazda lamp generates 2100 lumens or approximately 200 horizontal candle power. The heat equivalent of one kw-hr. is 3410 B. t u., hence, the 150-watt lamp liberates 515 B. t. u. per hour or approximately the same amount as the candle. As a matter of fact, the ordinary paraffin candle gives about 10 per cent less light than the standard candle used in photometry, and furthermore, the art of candle making has improved considerably during the past 100 years.

Mr. Stickney emphasizes the desirability of a glareometer. Such an instrument is certainly much to be desired but it seems as if its mechanism must be possessed of an almost human brain in order to integrate brightness, flux, location in the field of view, etc. in the same way that we do.

RATING OF CABLES IN RELATION TO VOLTAGE* HISTORICAL SUMMARY
(Subcommittee on Wires and Cables of Standards Committee);
DIELECTRIC LOSSES AND STRESSES IN RELATION TO CABLE FAILURES* (Roper);
ON THE MINIMUM STRESS THEORY OF CABLE BREAK-DOWNS* (Simons);
EFFECTS OF THE COMPOSITE STRUCTURE OF IMPREGNATED PAPER INSULATION ON ITS ELECTRIC PROPERTIES* (Del Mar and Hanson);
POTENTIAL GRADIENT IN CABLES† ((Middleton, Dawes and Davis);
CORONA IN AIR SPACES IN A DIELECTRIC‡ (Shrader);
ACTION AND EFFECT OF MOISTURE IN A DIELECTRIC FIELD† (Du Bois);
BIBLIOGRAPHY ON DIELECTRICS‡ (Simons).

Niagara Falls, Ontario, June 29, 1922

E. B. Meyer: As already stated by one of the writers, the general opinion in the past seemed to be that when the voltage of a circuit was increased the only requirements so far as safe operation was concerned, was to add more insulation to the cable.

Recent experience and research has developed the fact that the quality of the insulation and of the compounds used for impregnation have an important bearing on the safe operation of underground cables.

The thickness of insulation applied on cables has apparently been determined heretofore by a cut and try method. In several installations with which I am familiar, cables recently purchased have less insulation applied than some of the older installations operating at the same voltage. This seems to bear out the fact that either more insulation than necessary was originally provided, or that improvements in the quality of dielectrics have been effected.

In the operation of underground cable systems of voltages under 9000 comparatively little trouble is experienced. However, as soon as we pass this point and get into the range of voltages close to 20,000 which is becoming more extensively used, the number of failures per unit length of cable show a large increase over the number experienced at lower voltages.

In looking over the last report of the Underground Systems Committee of the National Electric Light Association in which was included a record of the cable failures during the year 1921 on cable systems at voltages ranging from 6600 to 25,000 volts, it is interesting to note that the average number of cable failures excluding those caused by electrolysis or external injury on a total of nearly 5000 miles of cable was slightly over 10 failures per 100 miles.

In a large number of systems in this classification operating at voltages over 15,000 the failures ran about 25 failures per year per 100 miles of cable. It is really seen from these figures that in order to reach what might be termed the "ideal condition" as cited by Mr. Roper in which he states that the burnouts of high-voltage cables should be no larger than for the lower transmission voltages and should not exceed one or two per hundred miles per year, radical changes and improvements will be necessary both in the construction and methods of handling underground transmission cables of the higher voltage class.

F. W. Peek, Jr.: I will limit my discussion to the data by Fernie given in Table I of Mr. Simons' paper. These data were obtained by measuring the break-down voltage on cables with inner conductors of various radii. The maximum stress or gradient on the insulation of such a cable is always at the surface of the inner conductor; the minimum stress is at the sheath or outer cylinder. The stress or gradient calculated from the break-down voltage varies with the size of the inner conductor.

*A. I. E. E. Journal, 1922, Vol. XLI, June, pp. 418, 423, 433, 439.
†A. I. E. E. Journal, 1922, Vol. XLI, August, pp. 572, 617.
‡A. I. E. E. Journal, 1922, Vol. XLI, September, pp. 689, 702.

The apparent strength of the insulation is greater for the smaller sizes of conductor. Exactly the same result is obtained with oil and air. The apparent strength of air for various sizes of conductors is readily obtained from the well established relation

$$g_v = 30 \left(1 + \frac{0.30}{\sqrt{r}} \right) \text{ kv./cm.} \qquad (1)$$

Where r is the radius of the conductor in cm.[1]

Data from Table I are given below with some additional calculations.

Data from Table I				Calculated from Equation (2)		g_v for air from equation (1)
R cm.	r cm.	Max. Stress at Cond. g_v kv/cm.	Stress at Sheath kv/cm.	Max. Stress at Cond. g_v kv/cm.	$R' = 1.1\sqrt{r}$	
1.13	.243	428	92	320	0.8	48
1.79	.527	335	98.3	250	1.30	42
1.25	.369	288	84.3	280	1.00	45
1.41	.527	257	95.6	250	1.30	42
1.62	.737	240	108.7	240	1.70	40
1.16	.527	219	99.5	250	1.30	42
1.70	.817	189	90 6	220	1.80	41

In the last column the stress is calculated for the same conductor arrangement as for the cable for the purpose of comparison. The apparent strength is greater for the smaller conductors as is the case for this cable.

The physical meaning of equation (1) is that when breakdown occurs the stress is not constant at the conductor surface but is always constant and equal to 30 kv./cm. at $0.3\sqrt{r}$ cm. from the conductor surface. This constant value of 30 kv./cm. is the strength of air, but a finite thickness must be stressed at or above this value before break-down can occur. This thickness is $0.3\sqrt{r}$ cm.

The break-down values for the solid insulation from Table I may be represented by the same relation. Thus

$$g_v = 100 \left(1 + \frac{1.1}{\sqrt{r}} \right) \qquad (2)$$

This means that the solid insulation breaks down at a constant stress of 100 kv./cm. at $1.1\sqrt{r}$ cm. from the conductor surface. It so happens that the radii of the sheaths, R, for the cables used in Table I have values approximately equal to $1.1\sqrt{r}$. This makes it appear that break-down occurs for a constant value of stress at the outer conductors.

C. F. Scott: I have some appreciation of cables, in a general way, I am not an expert, I am not going into this discussion in the way that the preceding persons have done.

I will look at the whole matter from a different standpoint, that is, with reference to the place of the cable in commercial engineering work. We see the large power houses which have been constructed—we marvel at the advance which has been made in the last twenty years, since turbines began to be factor in power generation, and yet, in the large cities, the investment in the cables which lie beneath the street, is comparable with the investment in the power houses, and the continuity of service may be as much dependent on cables as it is on the operating machinery of the power houses.

What do we find with regard to the change in cables in the last twenty years? It is about twenty years ago, if I recall rightly, that a cable of some 25,000 volts was installed, and so far as I know, has been reasonably successful and has been in continuous operation since that time. Yet, the number of cable installations, which have exceeded that voltage, have been very few and very recent, and neither in quantity or quality have they proved, I think, that they are yet 100 per cent perfect; and the one particular point I want to make is that the advance which has taken place in cables from the technical and operating standpoint, has been very mild and feeble, compared with that in other branches of the electrical industry.

We had presented, a day or so ago, the fact that in telephonic transmissions, efficiencies equal to the older efficiencies were obtained with wires of 1/10 the size, and that this was accomplished with cables containing something like ten times the number of circuits that they used previously.

That immediately raises the question why power cables have changed so little. Has the cable not been something that has been turned out by the mile, according to very ordinary sort of specifications? Has not the type of work, as has been presented here this morning, which is the theoretical research type, been of very slow progress and has not the theory advanced too slowly? Has not the practical application of that theory and the results of the research work which has been done on cables, to make better cables, not been very slow? In a word, are we not ten to twenty years behind the times in the real advance in power cables, in comparison with what has been going on in other fields of the electrical industry?

If that is so, it is a challenge to the electrical profession, to the theoretical men, to the cable makers, to get very busy in order that the cable, may take its proper part in performing its very important function in power distribution.

C. F. Proos: In a paper read before the Association of Electrical Central Station Managers in Holland, on September 30th, 1921, there were discussed certain factors that influence the dielectric loss in high-tension cables, with special reference to the tension at which ionization starts as influenced by changes of temperature.

The general characteristics of a paper insulated cable is shown in Fig. 1, where $\frac{W}{E^2}$ is given at different voltages. It will be noted that up to a certain value $\frac{W}{E^2}$ is constant; beyond that point $\frac{W}{E^2}$ changes due to the air becoming ionized; and at yet higher voltages it becomes nearly constant again, when the air is nearly totally ionized.

The time during which voltage is applied has influence on the measured value of dielectric loss, but only on the second part of the characteristic. Slow readings or low ionization give curves like No. III Fig. 5 instead of No. I.

Temperature has a large influence on dielectric loss as shown in Fig. 7. The curves show a minimum of losses, for all tensions, at nearly 37 deg. cent.

The ionization characteristic (Fig. 1) is changed by heating and cooling the cable. The ionization voltage runs up with temperature, and comes down, when the cable cools, to lower values than before. The higher the temperature reached, the lower the ionization voltage in the cooled cable, as shown in Fig. 9. There is a certain temperature of the heated cable, above which the ionization voltage in the cooled cable runs down rapidly (Fig. 10). Running the cable above this temperature makes the operating conditions dangerous, unless unusually thick insulation is used.

The power factor also changes with differences in temperature and is dependent on the range of temperature the cable has previously covered, as shown in Fig. 11.

In the original paper these results are discussed at length and it is shown that these changes in electrical values are caused and can be explained by the changes in volume and pressure of the

1. Peek, "Dielectric Phenomena in High-Voltage Engineering", p. 47.

small occluded air bubbles that are left in high-tension cables. Both the thickness and the pressure of the air bubbles change and ionization starts at different voltage in accordance with these changes. The expanding air pushes the fluid oil away at the spots of higher temperature which are also spots of highest dielectric loss and stress; these spots are dried out, the temperature rises and the resultant hot spot causes breakdown. The oil pushed away at high temperatures, does not come back to its former place when the cable has cooled down; the air occupies a bigger space than before, the pressure coming down accordingly. Hence at lower temperatures, the break-down voltage of the air bubbles is lower, and the heavy ionization which occurs is dangerous and may cause hot spots and consequent breakdown of the cable. Practise in Holland has confirmed this theory, several breakdowns having been noticed at the low temperatures which followed a period of heavy load on the distribution cables.

Ionization tension lowered by heavy loading of the cable comes back to former values in course of time. An average time for the recovery of a cable is 8 to 10 days. At higher temperatures recovery is faster. Curves taken on a recovering cable are shown in Fig. 12. It will be noticed from these curves, that the same cable can show nearly any possible form of characteristic according to the conditions (thermal and electrical) the cable has been subjected to before test. This explains most of the differences which have been experienced in checking dielectric loss measurements.

By special precautions taken in manufacture and in the materials used, the ionization stress in cables can be brought up to values of 40 kv./cm. or more and the influence of temperature changes can be reduced. (Figs. 14 to 19).

A cable always used at an operating voltage lower than the ionization voltage does not show hot spots; hot spots are caused by occluded air only, and will cause breakdowns sooner or later. Laboratory tests should be made on cooled cables after being heated up to operating temperatures. A proper knowledge of a cable's characteristics cannot be obtained unless its voltage characteristic is determined over a wide range of voltages. (Fig. 7). A test at one voltage only is insufficient; the ionization voltage must be known under all operating conditions.

The above tests were made at the Nedelandsche Kabelfabrik on lengths of 1000 feet or more with a special wattmeter at 50 kv./cm. The cables were heated by passing currents through the conductors, the sheaths being freely exposed to air. This is different from the American practise of putting cables in an oven until the insulation, is uniformly hot throughout, and more nearly represents operating conditions.

William A. Del Mar: In the course of preparing the Historical Summary, the Subcommittee noted that the first man to call attention to the importance of dielectric losses in cables was Mr. Philip Torchio. They found that in 1902 Mr. Torchio gave the results of measurements of dielectric losses on long feeder cables, and deduced the general laws which govern the variation of dielectric loss with voltage frequency and temperature.

Philip Torchio: Your reference to my work may be used as an illustration in answering Prof. Scott's very timely remarks which are more or less an attack on the slowness of American progress in cable development. As the Chairman states, I was the first to make tests and call attention to the importance of dielectric losses in cables in the Spring of 1902. My conclusions on the tests as I then reported were as broad and comprehensive and covering all features of the problem as we would enunciate them today, my report of 20 years ago stating that "the dielectric losses are approximately proportional to the frequency, to the square of the voltage and to a certain function of the temperature not yet determined. The temperature, however, increases considerably the dielectric losses."

I submit to Prof. Scott this fact, that while the fundamental principles of the importance of dielectric losses were clearly enunciated in 1902, practically nothing was done in this country in following up the subject until about 10 years afterwards when, in 1912, Mr. Roper was confronted with certain high-tension cable failures due to heating, and he then became persistent in urging that the study of dielectric losses in cables be seriously taken up and pushed forward. In later years, other operating engineers who experienced similar troubles vitally contributed to exert pressure to push the research. In this manner, through the efforts of both manufacturers and users either through independent or cooperative work, we have arrived at the large progress reported in these papers.

In reviewing these developments, I believe Prof. Scott will recognize the fact that until the need for improvements is felt either on account of failures of existing apparatus or inadequacy to give service, the theoretical research does not become of pressing importance. On the other hand, as soon as the operator experiences trouble, immediately the research becomes extremely vital. Hence, our experience with the study of dielectric losses in cables illustrates the great importance of the necessity of cooperation between users and manufacturers. The manufacturer must carefully study the experience of the operator and, on the other hand, the operating engineer must closely analyze his troubles and give the manufacturer the benefit of such experience.

H. W. Fisher: The writer will confine most of his remarks to Mr. Roper's criticism of American manufacturers and praise of foreign ones. Through correspondence from abroad, the writer knows that most of the so-called very high-voltage cables, concerning which much has been written in the technical press, have been operating, if at all, at much less than the designated voltage. Europe has apparently many engineers who try to keep their names before the public by advertising when they can, unusual work which is contemplated or supposed to be done abroad. When for any reason installation or actual operation at the stated voltage is delayed, a false impression is given, not only to the foreign, but also to the American public, of the actual accomplishment of foreign cable manufacturers and operators.

The writer has had access to actual tests of dielectric loss made in some of the cables abroad, and intended to be used at 33,000 volts, and the dielectric loss was so high that he can state with confidence that Mr. Roper would not operate the cables on his 33,000-volt system.

To be more explicit, I will state that the dielectric loss of this cable was over twice that required by Mr. Roper for his 33,000-volt cables. The cable was very well constructed and the physical properties of the compound were excellent, making very remote the possibility of transfer of the compound from one part of the cable to another. The manufacturer of this cable is a large concern with an excellent reputation and from the above information, it would seem that they are willing to sacrifice to a certain extent, dielectric loss in order not to neglect the other important considerations of cable construction.

R. W. Atkinson: The great questions brought to my mind by the subject of this meeting are "*What are the limits of the operating voltage of the cable, imposed by the voltage stresses in it, aside from the secondary effect of heating produced by dielectric losses*"? and "*What is the proper relation of insulation thickness to working voltage and what is the effect on the required insulation of the fact that the stresses are not uniform but are greater at the conductor surface?*" I will formulate some statements which I believe will be found fairly close to the correct answer to these questions. These questions will be discussed primarily from the standpoint of long continued stresses, though the answers apply in some measure to stresses applied for shorter time.

In his discussion, Mr. Peek has outlined an answer to these questions which is substantially the same as that which I have prepared but I believe that the matter is of such importance as to well bear a repetition, especially as my discussion is from a somewhat different viewpoint.

A theory departing very much from previous ideas has been

advocated by Fernie and has recently been given much publicity in this country. This theory has been effectively refuted in the paper presented this morning by Mr. Simons which leaves the way clear for the discussion to be made without further reference to it.

I will now consider the questions with which I have begun this discussion. Taking up the second question first, I believe the law for such dielectrics as are in the cables follows very closely that which has been developed by Whitehead, Peek and Ryan for air. That is breakdown will occur not when a certain average stress is reached nor yet when a certain maximum stress is attained but will occur when this maximum stress is imposed on a certain definite amount of the dielectric. The reason in the two cases is very similar. In the solid dielectric a condition of failure must be the liberation of a sufficient quantity of energy to cause disintegration of the dielectric at the point of failure. This disintegration may be mechanical, or due to heat, or to direct chemical changes and the electrical failure is likely to follow rather than precede these other changes.

As a direct result of this a cable with a large conductor though standing a higher total voltage will withstand a lower stress next the conductor surface than one with a small conductor, and the same thickness of insulation, but the difference is much less than would be calculated on the basis of maximum stress and indeed may be unimportant for fairly large changes of conductor size.

The answer to the other question follows directly. That is the dielectric strength will be substantially proportional to the thickness for the same ratio of maximum to average stress. The strength will not increase quite in proportion to the thickness because this distance through which the stress must exceed the critical value is of greater relative importance in thin insulation than in thick. By way of illustrating the magnitude of this effect, it may be cited that experiments with insulation 100 mils thick that have shown dielectric strength say eight times what might have been expected from ten mils, 1/10 as much, of the same material.

There is not time even to begin to outline reasons and data supporting this theory. I will give some cautions to prevent misapplication. One of the most common reasons that low values of average dielectric strength are found for thick masses of dielectric in proportion to those found for thin layers is the heating due to dielectric losses. In other cases there is a great concentration of stress with the thick mass due to the shape of the electrodes. Where means are not taken to prevent discharges over surfaces, the electrical oscillations produced thereby are likely to be proportionately higher for the higher voltage and for the thick insulation. In many cases the thick insulation though supposedly of the same quality, actually is of lower quality than the thin insulation. Thus, there are many ways in which tests will be relatively very unfair, to the thick insulation in spite of the fact that say the same precautions were taken in all cases. That is, on account of the greater difficulties introduced by the higher voltage many precautions must be taken that need not be taken for the lower voltage.

It must be borne in mind that there is essentially a large difference between tests made where the voltage is rapidly built up to the breakdown point than where voltage is applied for very long periods as in service or say in accelerated aging tests. It is believed that the same fundamental considerations will apply in both cases but that numerical values may be enough different to cause a very important difference in the ratios of strength for short time application and long time application for specimens of different thicknesses of insulation.

Where a cable has composite dielectric, it follows that the limiting voltage is reached when the critical stress is reached in a sufficient portion of either of the two dielectrics. This may be in the one having the greater stress. That is usually next the conductor—or it may be in the other if the ratio of the dielectric strength is greater than the ratio of the stresses. Incidentally, it may be pointed out that all multi-conductor cables having insulation on the individual conductors and a belt or jacket overall, are essentially of the class of composite insulated cables inasmuch as the filler materials constitute an essential part of the insulation and may be the source of voltage limitation on account of their low dielectric strength, in spite of the lower stress there than in the main body of the insulation.

In 1920 Mr. Roper gave a paper showing the results of experience on the Commonwealth Edison system with lightning arresters. In a way his overhead system became an enormous laboratory and the results of these observations were epoch-making and, we understand, have revolutionized our whole ideas on the protection of distribution circuits and the development of new and far better types of arresters and even in the means used for testing and judging the worth of an arrester. He has now begun work with another part of his huge laboratory, this time with his underground system.

Mr. Roper is trying in this vast laboratory of his whether American cables can successfully meet conditions which have never before been met when we consider both the thickness of insulation for the working voltage and the service conditions. Speaking first of cables for operation at 25 kv. and less, vast quantities of American cables with thicker insulation have met successfully these conditions and there is a good deal of experience in Europe under their more favorable conditions with insulation thicknesses less than are common in American practise. But we know of no operating experience anywhere with these thin insulations combined with American operating conditions.

It is important to remember that, though laboratory and factory tests on this cable give reasonable assurance of successful operation, yet there is a very fundamental difference between such tests and the actual practical proof by large scale commercial operation. Laboratory tests have a very great value, in fact are the foundation of development, yet very misleading conclusions may be drawn from these when they are not backed by proper large scale experience.

Separate mention may be made of three-conductor cable for operating at 33 kv. More than one lot of cable in England is understood to have been placed in operation at 33 kv. during the present calendar year. These cables are understood to have an insulation thickness of one-half inch between conductors and the same amount between the three conductors and the sheath. All of these cables have round conductors. One English cable with thicker insulation and also an American cable have been in operation at this voltage for a greater length of time but the present interest centers in these newer cables. It is of interest to compare these with the American cables which Mr. Roper has installed during the last year for the same voltage. His cable with a 350,000 cir. mils sector conductor and 19/64 in. plus 7/64 in. insulation and 9/64 in. lead has a diameter of slightly less than 3 in. With sector conductor and the same insulation as used in this frequently quoted English practise, the diameter would be about 3.04 in., or with round conductors it would be 3.32 in. or about 12 per cent greater than that of the American cables. Thus though the British have used relatively thin insulation between conductors, they have been so conservative by use of thick belt insulation and unwillingness to use sector conductors that these much talked of cables are materially larger than the American cables and have more insulation as a whole. The comparison in favor of the American cable is still further emphasized by the statement that with round conductor and the insulation thickness used in English practise a 3-in. diameter cable could not have a conductor as large as 250,000 cm. instead of 350,000.

However, aside from the fact that European practise regarding insulation thicknesses is not so different from American practise as appears on the surface, or is sometimes mistakenly supposed or taken for granted, there is plenty of difference between European and American conditions to make comparisons very difficult. In two most important ways do the English make very sure that

their cables are installed and operated so that they remain in exactly the original condition. In the first place, they take precautions about handling and bending the cable during installation that we understand are impractical under American conditions. Their cables are normally armored and it would be very difficult indeed to subject them to a serious amount of bending even if one wished to do so. It is true that English specifications are more severe in some particulars regarding bending test than is the American N. E. L. A. specification, though the English specification does not call for a low temperature at which the test is to be made, but we are not here concerned with the bending test which may be imposed under specifications. We are concerned with the actual installation conditions and with the fact that they are exceedingly careful to treat their cable with very tender care during installation and do not subject it to the degree of bending to which American cables are subjected. Thus the cable is installed in such a way that it remains in practically identically the condition in which it was originally made, and then it is operated with a maximum temperature of 55 deg. cent., or thereabout. This temperature limit is certainly not limited by dielectric losses unless these are far greater than is common in American practise. Under the favorable cooling conditions of installation directly in the ground, only very high dielectric losses indeed could cause limitations to this operating temperature. It is true that they are able to carry very heavy loads without exceeding this temperature but this limitation is quite surely because it is felt that the cables may deteriorate if heated to higher temperatures. This limitation may be nothing more than for instance the migration of the saturating compound due to fluidity at high temperature. If stresses are low we need not be concerned about that, but it is another matter if stresses are as high as allowable for cable in the original condition. We may very safely say then that whatever thickness of insulation is found satisfactory for conditions now obtaining commonly in American practise, a materially lower thickness will be equally satisfactory under conditions prevailing in England and other European countries, or conversely if our American operators can with like results use as thin insulation as can the Europeans, it means that they are getting better cables.

I believe that full study of the data will show that the American manufacturer has no cause to fear comparison of his recommendations or his product with those of European manufacturers. And let us give full credit to this operating company which is making this great experiment with its transmission system. Successful operation will be of material value to the operating companies of this country and to the industry in general. But let us conservatively remember that it is still an experiment, and let us not be too early in considering it out of the experimental field. And if this is concluded as a successful experiment let us remember the conditions under which it was made and not apply the results under still more severe conditions.

V. Karapetoff: This meeting represents a notable milestone in the development of cables and dielectrics. As an outsider, I note some tendencies which from my point of view seem desirable, and also a few remains of older undesirable tendencies in the methods of attack.

Perhaps the most desirable tendency is a steady, cooperative work, as contrasted with former sporadic individual efforts; also due respect to the work of preceding investigators, and a most excellent bibliography. This attitude alone vouches for the success of the enterprise.

Another desirable tendency is a change from looking upon a cable as a unit piece of apparatus, to a careful analytical study of its elements. I was once crossing the frontier between two European countries and had with me two presents, a fine silk shawl and a very heavy metal box. The customs inspector put them together on a scale, found the total weight, multiplied it by a coefficient, and told me what duty I had to pay. Many of the older experiments on high-tension apparatus remind me of that summary proceeding. A piece of cable is "shot," a result is obtained, and presented to the public for future digestion. The tendency in the present papers is distinctly away from that pernicious practise. The dielectric is separated into paper, petrolatum, moisture, and what not, and the properties of these materials are treated separately in a more or less scientific and rational manner.

Finally, I welcome most heartily the tendency to speak of the phenomena in dielectrics in terms of the recent ionic and electronic theory of electricity. I appeal to my fellow-teachers to see in this tendency an encouragement of our endeavor to present electricity to our students in terms of the ionic theory. In a few years our graduates will not be able to read Institute papers unless they become familiar with the electron theory.

As to undesirable tendencies one is exemplified by the Fernie theory. It reminds me of those old empirical rule-of-thumb formulas, and is a dangerous step backward. I was glad to hear a speaker oppose this theory.

The other tendency which I rather deplore is to extrapolate theoretical formulas derived from stresses within the elastic limit, and to apply them to the phenomena at the rupture of a piece of insulation. What would we think of a specialist in strength of materials who would use the results of the theory of elasticity in discussing the ultimate strength of a column or a beam? Could he legitimately use a theory which does not apply there? Take a continuous beam on three supports; as long as the stresses are within the elastic limit, the load can be increased and all of the stresses will be in proportion. But load the beam beyond the elastic limit, for example so that the middle support begins to yield, and you will get an entirely different distribution of stresses, unforeseen by the theory of elasticity.

This is apparently done in some of the papers presented today. The logarithmic formula which holds for dielectric stresses within the elastic limit, is being applied to the discussion of stresses which lead to the failure of a cable. I hope that this inaccurate way of reasoning will be gradually eliminated from our papers.

I would suggest to the Committee the necessity of extending our terminology in this branch of electrical engineering. Whenever there is progress in the art, we must not be afraid to introduce new terms. I notice that Mr. Del Mar used in his introductory remarks the expression "imperfection angle." This I think is a legitimate and useful term for characterizing a given cable. A cable has an imperfection angle of 5 deg., against some other cable with an imperfection angle of 9 deg. etc. We also need a new term to distinguish cables in which the ratio of radii is below 2.72 and above 2.72. It is rather awkward always to mention this ratio. Let us call one of them type A, the other type B, or thin and thick insulation, or something else, but let us not be afraid to introduce new names for these two types of cables.

B. Welbourn: Perhaps the best answer I can give to Mr. Fisher is to state one or two facts which are within my own knowledge as one of the engineers connected with cable work who has been right through the development from the early days of high-voltage cables in our country. We have a considerable quantity of 33,000-volt cable at work. In one installation, on which I have all the information, a large number of tests have established that the dielectric loss per mile at 50 cycles, with a conductor working temperature of 140 deg. fahr., 60 deg. cent., is exactly 2 kilowatt-hours. I think that you state your losses in terms of watts per foot, and unless my arithmetic is wrong, that is 0.38 watts per foot. I may say that considerably better results have been obtained since.

A cable manufactured by my company has been at work in England for the last two and one-half years, working with a stress of 5,530 volts per mm., as calculated by the Atkinson formula. There are 3-core cables in service working with 4400 volts per mm. I think you call it 44,000 volts per cm. in your phraseology.

I can state definitely that 44,000-volt three-core cables are commercially possible.

A great advance has been made in our country with regard to the question of dielectric losses. Forty-four thousand-volt 3-core cables can be supplied which will have a power factor not exceeding 1 per cent, up to a working temperature of 130 or 140 deg. fahr.

A good deal of attention has been given today to Mr. Fernie's minimum stress theory. He is a friend and, until two years ago, was a colleague of mine. He developed his theory about 1914. and the results which he has published in the *Beama Journal* are based on experimental work done at least seven years ago.

At the time Mr. Fernie reached his conclusions, he caused a great deal of discussion in my company, as you may imagine and I might say that his results have never been accepted by my company. I think that much later work which has taken place since Mr. Fernie left the company, and went out of the cable business has shown that his theory has to be provisionally laid aside until a completely new lot of data can be accumulated on cables of the latest manufacture.

I would therefore suggest to Mr. Simons and the other gentlemen who have been discussing Mr. Fernie's theory that they lay it aside for a time, until they have done further experimental work on up-to-date cables.

I have been rather surprised in looking over your literature on cables, to see how little attention has been paid to the subject of the thermal resistivity of the insulation. It is the same in our country, but to the operating companies, and to the engineers who have to prepare the specifications for cables, I would strongly suggest that they call for very stringent guarantees on the thermal resistivity of the cables they are buying, whether they be for high or low-voltage work.

D. M. Simons: In considering Fernie's data, I mentioned that it was unfortunate that his tests did not include a greater range of the ratio R/r, or D/d. The paper by Messrs. Middleton, Dawes and Davis contains a valuable contribution in this respect, since their breakdown tests cover four times as great a range of D/d as Fernie's. It is interesting to see that their tests show that the minimum stress is by no means constant.

The authors have apparently concluded from the data of their Tables 1 and 2, that the maximum stress at breakdown is a constant for cables in which D/d is equal to or less than 2.72. This does not seem to be justified as a definite conclusion since there are appreciable variations in their test values, and in fact, the variations are about half as great as those of their average stresses.

I feel that the comparison of the maximum stresses in three-conductor cables as calculated by the so-called old and new methods is open to considerable criticism. In the first place, they assume in this comparison that the maximum stress at breakdown is a constant, and the same for single-conductor and three-conductor cables. Secondly, the so-called old formula for a stress in three-conductor cables gives obviously a stress considerably too high. The actual cable consists in one leg of two parallel cylinders with the delta voltage between them, and for this condition the old method substitutes one cylinder of the correct diameter, surrounded by a large concentric cylinder, with the same insulation thickness and the same voltage. It is well known that the maximum stress in the former case is always considerably less than the latter. The accuracy of the new method has been so thoroughly substantiated that the tests shown by these authors do not tend at all to disprove this method, but rather to show that the maximum stresses occurring at breakdown in the three-conductor cables tested by them were much lower than the maximum stresses in the single-conductor cables tested.

Mr. Welbourn has apparently obtained a meaning certainly not intended by Mr. Fisher's remarks. Mr. Fisher by no means intends to imply that none of the high-voltage cables mentioned in the foreign press were in operation, since we have every reason to believe that certain ones are under full rated voltage.

On the other hand, he has attempted to point out that it seems quite sure that many of the described installations are not in operation. I might mention specifically the cut which appeared about a year ago in the *Electrician* showing a large three-core cable "for 66,000 volts." Our information seems quite definite that this cable is not in actual operation, but is merely a short experimental length.

Mr. Welbourn has apparently replied to Mr. Fisher's remark about the dielectric loss in a foreign cable by mentioning the very low dielectric losses in British cables, I am sure that Mr. Fisher's comment was by no means meant as a criticism, but quite the contrary, and that he merely desired to show that certain foreign manufacturers at least did not consider it necessary or advisable to go to extremely low dielectric losses.

J. B. Whitehead: In discussing the potential gradient at the surface of the central conductor of the cable it is perhaps worth while to recall that the value which we use is based on the elementary laws of electrostatics acting in a perfectly continuous medium, such as the ether.

We should remember that when we introduce a dielectric we may through the polarization modify the forces existing before its introduction. For we know that even a perfect dielectric is made up of discreet molecules and that under electric stress the component charges of these molecules are drawn apart. Remembering also the space separation between molecules themselves, it is not difficult to picture such a space arrangement of charges, around a circular conductor as would alter the value of the electric intensity pertaining to a continuous medium. For example we may imagine the dielectric in a single-conductor cable as arranged in concentric layers of molecular thickness, and the component charges separated radially under the electric field. In each layer the inside charge would be nearer the central conductor, and owing to the space separation, would tend to lower the normal value of the intensity in the next inner layer. The amount of this lowering would depend on the radial and circumferential space separation of the charges, but reasoning in this way, it is not difficult to picture the stress in the layer next the central conductor as being reduced to a value comparable with or equal to that in the layer next the sheath. This would account for the evidence that cable breakdowns do not always begin at the center, and would permit us to think that a perfect dielectric at least may have a definite dielectric strength. There is good reason to believe that the gradient necessary to ionize a molecule has a definite value. But air and oil and perhaps other dielectrics always do begin rupture at the center as in the corona. Does not this upset the foregoing suggestion? Not necessarily, for neither air nor oil is the perfect dielectric we have pictured. In each of them, in air particularly, free ions, that is, independent charges, are always present in a certain quantity. These charges, unlike the neutral molecules may move freely in the electric field and so may cause a still further modification of the gradient at the center. It is in some such phenomena as these that the explanation of the peculiar law of corona will ultimately be found. It is probable that we shall never attain the perfect dielectric, but it would appear that the stiffer cable compounds would offer less freedom of movements to independent ions, and so would be less liable to departure from the ideal structure in this respect.

Here, however, new troubles await us, for we encounter conducting filaments, moisture particles, and other departures from homogeneity, any one of which may cause a further modification of our fundamental expression for potential gradient. Consequently, it is of great importance as already pointed out by Professor Karapetoff, that in analyzing the problems presented in cable construction, every care be exercised to separate all the elements entering. The occurrence of corona, or more properly, ionization, in thin air layers, has been recognized for some time.

Suspected only at first, its presence was next indirectly shown in the break in the dielectric loss curves of cables, and subsequently its presence has been made visually manifest in air layers between glass plates. Mr. Shraders' power factor curves on one sheet of insulation and an adjacent film accentuate sharply the influence of this state of ionization. It is important to note, however, that his curves are all plotted with the average potential gradient as abscissas, and consequently they do not express the behavior of the air alone, but only the combined behavior of insulation and air. It is for this reason that the rise in the power factor curves is gradual for the thinner air films, and steeper for films of increasing thickness. Ionization begins at a definite value of potential gradient, and consequently the power factor curves plotted against gradient in the film, would all of them show a sharp ascent at the critical gradient.

The sharp maximum of power factor indicates that above the critical gradient the normal charging current increases more rapidly than the ionization loss, and suggests that the principal loss is due to the process of ionization, rather than to a resulting resistance of the air film

W. C. Hayman: Mr. Roper, in his paper, has given us some very good data on dielectric losses and stresses on paper insulated cables. His conclusion, however, that in low-loss cables the temperature is limited as in low-voltage cables by the temperature which the insulation will stand without deterioration, does not agree with results we have obtained from a number of tests. We have found that the breakdown voltage of low-loss cables decreases with increase of temperature. The average breakdown voltage will decrease between 25 deg, and 100 deg. cent. as much as 25 per cent.

We should also make a study of the effect of high temperatures on compounds used for impregnating high-tension, low-dielectric loss paper-insulated cables, before we make any change in the present standard temperature ratings.

Referring to Mr. Simons' paper regarding Fernie's theory, it would seem that more experimental data are necessary before we discard some of the older theories regarding stresses in the insulation. We have found from tests that breakdown voltage on small conductors is less than on large conductors where the insulation thickness is the same. As the breakdown varies so widely, however, on samples cut from the same cable, it is necessary to make a large number of tests.

William H. Cole: In cable specifications with which I am familiar, dielectric losses are specified to be relatively low, but no other essential quality is to be unduly sacrificed on that account. I believe certain manufacturers have been neglecting some of these other qualifications of good cables. In one case at least, while continued reduction in dielectric losses has been effected, the saturation of the paper dielectric has become less perfect. I do not refer to longitudinal migration of compound with which many engineers are familiar, but to continual radial absorption by the paper of compound from the filler spaces. Such cables are apparently well saturated when they are delivered and remain so while held in storage. After being in operation from one to two and one half years, some of these cables develop serious voids in the filler spaces, so that we are now meeting with trouble due to ionization in the central part of the cable.

Tests have been made which indicate that ionization has an oxidizing effect on the compound. Stethoscope tests show that the used cables have a larger percentage of voids, than unused sections from the same original lot.

On the whole it appears to be a question whether or not the manufacturer in arriving at low dielectric losses has acquired sufficient knowledge of the characteristics of his impregnating compound, how much compound he puts into his paper, how much he leaves in the filler spaces, and how long that compound will remain in the filler spaces. The importance of this subject was realized years ago—that compounds must not only be introduced into the cable to a sufficient extent to fill all voids, but that there shall be no chemical or other action within the cable after the cable is placed in service.

On the subject of d-c. testing of cables the class of cable referred to failed recently under a d-c. routine test. The faulty section was carefully examined disclosing the radial absorption effect, the ionization of the voids and the oxidation of the compound. The cable under test had been in continual service, was supposed to be in a sound condition, and the operating pressure between conductors had been of the order of 24,000 volts. The d-c. test voltage was 40,000 volts or less than two times the a-c. operating pressure. On the basis of the factor of 2.4 the cable failed at a voltage much less than the d-c. equivalent to the a-c. operating pressure. The condition of the dielectric at the point of failure seemed to show conclusively that so called, "spitting" and re-healing of the dielectric had been taking place for some time under a-c. operation. The only conclusion to be drawn is that d-c. voltage is probably more effective in breaking down incipient faults than a-c. voltages and that the ratio of 2.4 between d-c. and a-c. holds good only for dielectrics in perfect condition.

It may be of some slight interest to know that tests on high dielectric loss cables have been made for the purpose of determining whether or not the potential gradient is very much altered by temperature gradients, and while it is of no particular interest today, since no one uses high loss cables willingly, it has been found possible, with sufficient fall of temperature between the copper and lead, to change the distribution of the potential, so that the outer layers receive very much higher stresses than would be calculated for uniform temperature. This may be a possible explanation why some of the old type high loss cables could become so badly charred before final breakdown.

G. B. Shanklin: Mr. Roper's study of current carrying capacity and critical temperature is based on an average duct radiation curve taken from a paper by W. S. Clark and myself read before the Institute in 1919. Available data on duct radiation constants are very meager and our curve was given merely as an illustration with no intention of introducing it as a standard. Since then a few additional data are available and a closer study of our original radiation curve indicates it to represent about 25 per cent better thermal conditions than actually exist in the average duct. Our original "hot spot" radiation curve more nearly represents the true average curve than our original average curve does.

It was with some misgivings, therefore, that I noted Mr. Roper had based his calculations on the average curve and it is surprising to find how well his practical observations and experiences check his calculations. I believe this is accounted for, at least, in part, by the fact that his dielectric loss values assume a uniform temperature through the cable cross section, equivalent to the copper temperature whereas, in actual practise the temperature is graded through the cable cross section, giving a lower dielectric loss than he assumed.

A standard average duct radiation curve would prove useful and if one is ever adopted it would be much better to represent the temperature drop from sheath to ambient soil. The curve would then be independent of the type of cable placed in the duct, except insofar as influenced by sheath diameter, which under ordinary conditions is a factor of no more importance than several others that are ignored in this "short-cut," approximate method.

Mr. Roper's statements regarding the variation of dielectric loss over lengths of cable might lead to misinterpretation. I believe he referred only to high loss cable of the rosin-oil-filled type. The better grades of low loss modern cable do not show such wide variations with length.

An interesting feature brought out by Mr. Roper's study of critical temperature is that, although the Institute temperature rule of 85 deg. cent. applies very well for the old type, high loss cable it is too conservative for the new type, low loss cable.

I have only one conditional exception to take with Mr. Roper's conclusions. He shows quite clearly that the quality of cable

insulation has been improved to a point whereby there is little danger of cumulative heating under normal operating conditions. He also shows that this new type of cable meets the standard high-potential test with ease. On the strength of this advancement he recommends that insulation thickness be reduced. There is no doubt but that the thickness used in this country can be safely reduced, but I feel that Mr. Roper has overlooked one important factor, and that is internal ionization.

The state of the art has progressed to a point, now, where internal ionization will be the limiting feature in any further reduction or gain. It is to be regretted that more is not known about this feature. We know that when voids or gas spaces are present in a cable that ionization occurs when a certain value of stress is reached. The conditions under which this ionization is likely to occur in service, its nature, whether it continues indefinitely and the amount of damage it can do is not clearly understood. We are at present making a study of these factors and hope to throw some light on them in the near future.

Ionization cannot be ignored. No matter how compactly made a new cable may be and how tightly the sheath is applied, voids form in service. Expansion and contraction loosens the lead sheath, causing it to "crawl" to a more or less extent, thus forming voids. Under laboratory test conditions these voids just under the sheath are ionized at a stress on the insulation (minimum stress) of about 14.0 kv./cm. What occurs in actual operation when the minimum stress exceeds 14.0 kv./cm. we do not know yet. Our work thus far indicates that ionization usually starts first, next to the sheath and not next to the conductor as previously assumed, although we are not prepared to state this conclusively.

Mr. Simons' paper on the dielectric strength of cables is too theoretical and speculative to be of practical application. Papers of this type are interesting and help us form a better mental picture of what might happen in a cable at breakdown. What actually happens is another story and probably involves too many factors to be so simply explained.

The mechanics of breakdown in gases is now fairly well understood and the parallel problem of liquids is well on the road towards solution. Gases are homogeneous and readily applicable to theoretical study. It is but natural that they should first give up their secrets. Liquid insulations are not so homogeneous but far more so than solid insulations. Investigators began to make real progress with the mechanics of breakdown in liquids only after the factors introduced by foreign impurities, such as moisture, dust, etc., were recognized and eliminated.

The same principles will have to be applied to a study of the mechanics of breakdown in solids. One of the greatest difficulties is in obtaining even an approach to homogeneity in solids. We must first learn something about the theory of breakdown with simple homogeneous solids in a parallel field and explain why the breakdown stress usually depends upon the thickness of insulation. Later we can go to more complicated built up commercial insulations in parallel fields and finally to cables, in which the non-parallel dielectric field adds further complications. What is needed at present are more actual breakdown data on cables, such as published by Fernie, and the very interesting data presented at this meeting by Messrs. Middleton, Dawes and Davis.

The paper by Del Mar and Hanson impressed on two counts, as we have done work along similar lines. Their theoretical study of dielectric loss is clearly and remarkably put forth and agrees with measured results better than any of the several theories that have been advanced at various times.

Several years ago we found by trial that the equivalent dielectric circuit could be closely represented by an arbitrary circuit similar to their Fig. 2. The component which they designate in their formula as "resistivity of cellulose fibers," however, should be called, "unknown factor," for it must surely represent more than the resistivity of the cellulose fibers. (It probably represents also the moisture resistivity.) The effect on dielectric loss of this component is small. I fully agree with their statement that dielectric loss is largely determined by the resistivity of the impregnating compound, for we have made numerous measurements that verify this in every particular and have found much the same relation between power factor and compound resistivity as given in their Fig. 3.

In one other respect, our work verifies theirs. The conductivity of compound alone, and hence, the power factor and dielectric loss of finished cable, gives every appearance of being mostly due to ionic conduction. It may not be true ionic conduction of the electrolytic type but it is some sort of uniform migration or transfer of charged particles such as metallic conduction. One of the best proofs of this is the almost exact agreement between d-c. and 60-cycles a-c. resistivity of compounds at temperatures above their melting points. Divergence occurs only at lower temperatures where the compound is in solid form. There is a sharp upward break in the resistivity curves when the solidifying temperature is reached.

The conclusions arrived at by Messrs. Del Mar and Hanson concerning dielectric strength are not so convincing. They attempt to explain the dielectric breakdown by this same theory of ionic conduction. If they are referring to slow breakdowns of the accumulative heating type their theory holds quite well, such failures should be called conduction breakdowns, but the term dielectric strength is recognized as applying only to those breakdowns that occur soon after the test voltage is applied and before accumulative heating takes command.

Under these conditions there is no relation between dielectric loss and dielectric strength of cables. Quite often cables having the lowest dielectric loss also have the lowest dielectric strength and vice versa. Still more convincing proof that the conduction and dielectric strength are unrelated is furnished by tests on the compound alone. Here, there are no cellulose fiber barriers, the charged particles have a free path between electrodes. One would naturally expect the relationship to be brought out more distinctly than in cables. The results, however, are even more divergent than in cables. Compounds having low resistivity often have high dielectric strength. If moisture or dust is added to a compound of high resistivity its dielectric strength can be reduced to a negligible value without effecting its resistivity at all. The resistivity of any compound varies enormously with temperature while its dielectric strength is effected hardly at all by temperature. This same temperature characteristic holds, approximately, for solid insulations.

I have studied dielectric strength for a long time, and have never found a theory that applied better than the old analogous theory of mechanical impact stresses and strains.

There appears to be a tearing apart of the molecular structure similar to mechanical rupture. Some materials are electrically brittle and some electrically elastic, analogous to mechanical brittleness and elasticity.

One of the most vital factors appears to be concentration of stress, set up by local high frequency. As an illustration, a poorly filled cable can be considered. Every one knows that a poorly filled cable has relatively low dielectric strength. This is due to concentration of stress, set up by local high frequency. When the applied voltage reaches a certain value, the voids in the cable cross section are ionized. At first it is merely a faint glow but as the voltage increases there is an increase in intensity of discharge and appearance of local high-frequency oscillation. The localized stress thus caused tends to start rupture and final breakdown. This might first start at the conductor, at the sheath or wherever the voids happen to be located.

Mr. DuBois, in his present paper advances a theory of dielectric loss somewhat at variance with that of Del Mar's and Hanson's. He attempts to account for dielectric loss as due to a certain peculiar behavior of moisture content. I believe if both theories were combined in their proper proportions a very good

working theory would be produced. The whole trouble seems to be that Del Mar and Hanson ignored moisture while Du Bois over-emphasized it. It is only in cable not thoroughly vacuum dried that the moisture component of dielectric loss is comparable with that component produced by the conductivity of the impregnating compound. I am certainly inclined to agree with Del Mar and Hanson in their conclusion that the last named component predominates in modern, low loss cable. All of our experience points in that direction.

Messrs. Middleton, Davis and Dawes deserve a unanimous vote of thanks for their splendid paper and the admirable way in which they have handled dielectric strength, a subject involving many, as yet, unknown factors. Their empirical results are original and impressive. It will be interesting to see how well they stand the test of time and additional trials.

If Mr. Middleton had looked up a paper on cables presented before the Institute in 1917 by W. S. Clark and myself he would have found evidence supporting his conclusion that automatic grading due to voltage stress and temperature distribution is of negligible amount.

Mr. Shrader's paper on "Corona in Air Spaces in a Dielectric" does not leave much room for doubt concerning the cause of the peculiar and abrupt change in dielectric loss that occurs in practically all commercial forms of solid dielectrics when the voltage is increased. It is, as we have always contended, due to ionization of the entrapped gas. It is to be regretted that Mr. Shrader did not include data on permittivity, temperature, etc., which would have enabled those engineers who have worked along similar lines to make a better comparison between his work and theirs. His method of presenting results is, in every other way, exceptionally good, but I do not agree with his conclusions that these results cannot be theoretically applied.

J. L. R. Hayden: In our investigation on insulated materials during the last few years we made the same observations, which are in good agreement with Mr. DuBois explanations on the effect of moisture in insulating materials. We have been able to reproduce experimentally some of the phenomena discussed in the paper in such a manner that they can be visually observed. For instance, the action of moisture particles in forming threads and bridging between terminals, is illustrated in Fig. 1 of the paper. This can be shown conveniently in the following manner. As insulating materials we use a light colored viscous oil; as terminals two spheres of 2.5 cm. diameter and 1 cm. distant, and impress about 10,000 volts between the spheres, that is, much less than the voltage which the oil gap would stand, Then a small amount of moisture is dropped on the oil by a dropper, in small drops. These drops can be observed to drop slowly through the oil, until they approach the electrostatic field. Then they are rapidly sucked into the field, and each drop elongated into a thread, and the thread lengthens, until it bridges between the electrodes. Then a flashover and the thread is destroyed by turning into steam by the heating effect of the current through it. In this manner flashes occur for a considerable time in intervals of a few seconds by drops entering the gap, lengthening into threads and bridging the gap.

Very interesting and suggestive also are the motions of the drops, which depend on their position in the electrostatic field, and on the nature of the field, whether unidirectional or alternating.

N. L. Morgan: Mr. Simons has mentioned several theories which attempt to account for the breakdown of single-conductor cables having the radio R/r greater than 2.72 and he has also suggested another theory to explain the results obtained by Fernie. After reading his paper, I do not feel entirely satisfied with his explanation. I think that it is an advance over the other theories that have been suggested but do not think that it has been carried far enough.

I do not see how insulation can be overstressed and at the same time not destroyed. Several investigators have shown that so-called "overstressed insulation" is really due to temperature rise, and the effect eliminated after a period of rest. It seems to me that the breakdown of single-conductor cables, having the ratio R/r greater than 2.72, is due to change of dielectric constant of the portion of the insulation near the conductor. As a voltage is applied to the cable, the stress in the portion of the insulation near the conductor increases and consequently the increasing dielectric loss causes the temperature to rise. Although the a-c. dielectric constant does not change below 50 deg. cent. it does vary considerably above 100 deg. cent. If, therefore, the inner portion of the insulation is several degrees hotter than the portion near the lead, we may have the equivalent of a cable with graded insulation and the cable would withstand higher voltages than would be expected.

This also explains Fernie's statement that small conductor cables withstand higher maximum stress than large conductor cables with the same insulation wall.

From the above one might think that the greater the dielectric loss of a cable is, the hotter it will get and therefore the greater will be the breakdown voltage of the cable. But as mentioned above, breakdown is really a charring of the dielectric, that is, a strictly physical phenomenon, and the cable with the greater dielectric loss will reach this charring temperature first.

When voltage is applied suddenly, the heat generated near the conductor where the stress is greatest has not sufficient time to be conducted away and the grading effect will be much more marked than if the voltage is increased slowly and the heat given time to be conducted to the sheath. That is, a cable will withstand a higher voltage when it is applied quickly than when the cable is subjected to long period test, which has been found to be the case in practise.

It seems to me that a satisfactory theory of dielectric breakdown, will not be arrived at until we take all the factors into consideration. The theory cannot be based on only one class of observations, but must be based on the temperature of the dielectric, its dielectric loss and constant, its insulation resistance, its specific heat, the thermal conductivity, its shape, its dimensions, and the inter-relation of these different properties. When all these things have been taken into account, then we will be in a position to formulate a theory of dielectric breakdown.

C. P. Steinmetz: An extensive investigation of this problem of the mechanism of the breakdown of solid insulation, has been carried out during the last few years in my laboratory by Mr. Hayden and his assistants, in which we derived the conclusion, or rather, are forced more and more to the conclusion that there exists no such thing as a definite breakdown voltage or breakdown gradient of solid insulation.

It seems to look more and more as if the electrical breakdown of solid insulation under electrical over-stress is not analogous to the mechanical breakdown of a structure under mechanical overstress, but is a phenomenon of an essentially different nature, and different character, and is related to the electrical characteristics of the third class conductors. I have discussed this type of conductor on a number of occasions, the so-called pyro-electric conductor. It is a type of conductor little studied. It is characterized by a volt-ampere characteristic in which over a certain range of current, the voltage decreases with increasing current; so that in such a conductor, if we impress a voltage and gradually increase it, the current passing through the conductor first increases proportionately to the voltage, then begins to increase more than proportionately to the voltage, and finally, the resistance decreases with increase of current at such a rate that the voltage does not further increase, but the current continues to increase. A further increase of current results in a decrease of the terminal voltage across the conductor, and with increase of current, the voltage decreases to a minimum. Beyond this the voltage may again increase slightly. That is, in such a conductor there is a maximum voltage point at a certain intermediate current. The results of our investigation seem to show

that what we call a solid insulator, is, at least in many cases, a third-class conductor—a conductor of a type in which the current at the maximum voltage point is extremely low.

Considering then the solid insulator as such a third class conductor. By impressing constant voltage on it, and gradually increasing the voltage, you will find that the current, passing through the insulator, increases, first proportional to the voltage, and then more than proportional, until the maximum voltage point is reached, and there the current runs away, rapidly, practically instantly rises, up to the short-circuit current of the voltage supply, which means the destruction of the conductor by heat and the elimination of all that can be seen. We have succeeded, by limiting the power, to carry these volt-ampere characteristics of the insulator beyond the maximum voltage point, and observe that part of the volt-ampere characteristic, where the increase of current means a decrease of voltage, where, as we would speak of insulators, the insulator is over-stressed. We find that at the maximum voltage point, which would be considered in general as the breakdown voltage, the disruptive strength of the insulator is not impaired, and we may go materially above this, and still have the insulator unimpaired, no change, no damage. It is the unlimited concentration of energy, resulting from this characteristic at constant voltage supply, which leads to the destruction which we call breakdown.

But, by limiting the energy, we have been able to go beyond the maximum voltage, and we have been able to study the behavior of solid insulation in this range.

From this it follows that in dielectric fields where the shape of the field is such as to limit the energy which can be concentrated in an overstressed portion of the dielectric, as is the case, for instance, with a cable with a high ratio of external to internal diameter,—with such a structure a part of the insulation can be stressed above the so-called breakdown point of the insulator without changing the insulation.

In this case the logarithmic law of voltage distribution does not apply any more.

You see all these are conclusions which have been brought out very nicely in a number of these papers. Furthermore, it follows that the rupturing voltage of a solid insulator, with continuous voltage and alternating voltage, are in a constant relation, and this relation depends on the nature of the insulator, and this seems to offer a possibility of the study of actual voltage distribution in the insulator, not merely at breakdown where the voltage distribution really means but little, but before and after the breakdown, and so get some idea of the mechanism of the breakdown.

It follows, for instance, that with regard to the overstressed portion of the insulator, the voltage gradient does not collapse, but remains finite, though lower than in the portion of the insulator which is not overstressed.

We may consider the maximum voltage point of the solid insulator as third-class conductor, as the breakdown point. However, this maximum voltage point of the volt-ampere characteristic is not a constant, but depends on very many conditions. It depends on the nature of the insulator, on the energy developed in the insulator, or near the insulator; on the heat conductivity and on the heat storage capacity of the insulator and of all surrounding material, and also on changes taking place in the insulator with temperature, etc. Mr. Roper's paper was interesting in showing a number of features that bring this out, although I have not had time yet to numerically check up these figures.

There is still a large amount of work which will have to be done, before we can really be perfectly certain of this conception of the solid insulator as a third-class conductor, by which the electrical volt-ampere characteristics determine the behavior of the insulator in the electrostatic field. There will still have to be much experimental work done, and the conclusions which we derived therefrom, verified; but it is to be hoped, at a meeting similar to this, it will be possible for Mr. Hayden to present a paper on the mechanism of breakdown of solid insulation.

G. A. Anderegg: In connection with the problem of dielectric loss in power cables it may, perhaps, be of interest to make a brief statement regarding similar losses in telephone cables at frequencies higher than those customarily considered in power circuits.

Telephone transmission ordinarily occurs at voltages far below the limiting strength of the insulation, and the entire power loss in such cables normally has no appreciable effect upon their temperature. In such cases the dielectric losses are of importance, therefor, not from the standpoint of heating or of breakdown strength but from the standpoint of attenuation, especially in case the cables are artificially loaded with inductance or are operated at the high frequencies used for "carrier" transmission, when the dielectric loss may add substantially to the total power loss and transmission loss. It is, therefore, important, especially in long loaded cables, to take special precautions to have the dielectric loss as low as possible.

It has long been recognized that the capacity and insulation resistance as measured with direct current by means of a galvanometer do not accurately represent these properties for a cable operated at frequencies of hundreds or thousands of cycles per second. Great numbers of measurements of capacity and dielectric loss of circuits in telephone cables have, therefore, been made by means of a specially designed bridge, briefly described by G. A. Campbell in the *Electrical World* and *Engineer*, April 2, 1904. It has been found convenient to express the results of dielectric loss measurement in the form of the conductance of the circuit; *i. e.*, the admittance of an actual circuit having capacity and dielectric loss is represented as if it consisted of a pure ideal capacity shunted by a conductance. To make a ready comparison of different circuits, it has been found convenient to consider for each the value of the "damping constant" $G/2C$, in which G is the conductance in micromhos and C the capacity in microfarads. This expression appears in one form of the attenuation constant for a loaded circuit, and when its magnitude is known for the desired frequencies it serves to indicate the quality of the insulation from the standpoint of dielectric loss.

With the types of insulation most commonly used in telephone cables it has been found that the conductance is approximately proportional to frequency throughout the ordinary range of telephone frequencies, though increasing somewhat more rapidly than proportional to frequency. It is independent of the applied voltage so long as this is kept well below the breakdown strength of the insulation, as is the case in normal telephone operation.

Since the conductance increases with frequency it follows that for a given effective voltage the dielectric loss is greater with a complex wave form than with a pure sine wave form, because the higher frequency components of the complex wave form act upon a higher conductance and, therefore, contribute a greater dielectric loss than they would if conductance were independent of frequency. This fact may have some bearing on the advantage of a good wave form for power transmission in cables.

In many telephone cables low capacity and low dielectric loss, rather than high breakdown strength, are controlling requirements. The design of such cables differs greatly from that of power cables, the commonest form of insulation being air and dry paper without impregnating material, only enough paper being used to give the spacing of wires needed to secure the desired capacity and the necessary firmness to make it possible to handle the cable successfully during installation. Such construction makes possible a very low dielectric loss. In some cases the power factor, or sine of the "imperfection angle" at 1000 cycles per second may be as small as 0.002, or sometimes even less.

Changes in design or treatment which tend to increase the insulation resistance for direct currents usually tend also to

decrease the conductance for alternating currents and to decrease the excess of the capacity at low frequencies over that at high frequencies, though there are no definite relations between these quantities. In the ordinary ranges of working temperature the conductance of the usual types of telephone cables increases with increase in temperature, though in many cases there is a temperature of minimum conductance, below which a further decrease of temperature again results in increased conductance. Certain insulators, for example rubber compounds and gutta percha, in many cases show a very markedly higher conductance at temperatures approaching the freezing point of water than at more ordinary room temperatures, although their direct-current insulation resistance is much greater at the lower temperature.

W. D. A. Peaslee: With reference to the paper by Messrs. Middleton, Dawes and Davis, there are several very interesting points brought out that add materially to the large amount of data that has accumulated during the last few years leading to a serious question as to the validity of our past theories with regard to the mechanism of breakdown of a dielectric.

It would seem that it is time for a very serious consideration of our past theories in the light of the accumulated evidence of the last ten years of investigation in the field of the so-called dielectrics to see if there is not something fundamentally wrong with our ideas regarding these materials. For sometime I have been drawn very positively to the feeling that there is no such thing as a dielectric; that the substances we have ordinarily

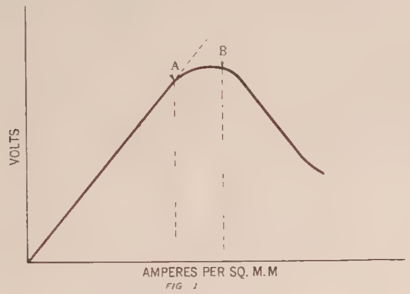

FIG. 1

regarded as dielectrics are merely conductors of enormously high resistivities and furthermore the accumulating data secured by means of high-voltage direct current with considerable energy available, points to the conclusion that most of the so-called dielectrics are conductors wherein at some point of the volt-ampere characteristic the volt-ampere coefficient changes from positive to negative following more or less the curve shown in Fig. 1. Dr. Steinmetz' remarks at this meeting have strengthened very greatly the author's convictions in this matter. If we refer to Fig. 1 we note that for a certain increase of current the voltage across a given path of such an insulating material (so-called dielectric) increases in proportion to the increase in current density. At the point "A" on the curve this increase departs from a strict proportionality, the coefficient steadily decreasing until at B the coefficient has become O and an increase in current density does not entail an increase in voltage. Beyond the point B an increase in current density actually occurs with a decrease in voltage across the conducting path.

We have, in the past, rather accepted the mechanism of dielectric breakdown as expressed in the old rule "whenever for a finite period of time the dielectric flux in a given dielectric exceeds a certain critical value for that material the dielectric is destroyed." I think that this theory is subject to very positive challenge in the light of present accumulated data. The acceptance of such a theory of breakdown has led to the discrepancies in interpretation of observed data, such as have been brought out in the paper by Fernie's "Minimum Stress Theory" and other theories discussed in these papers.

Let us for a moment examine what occurs in a cable as voltage is applied between the conductor and sheath. Admitting for a moment the hypothesis that the so-called dielectric is merely a conductor of the class described of extremely high resistivity, assume a conductor of radius r surrounded by an insulating material whose volt-ampere characteristic is given in Fig. 1 which is in turn surrounded by a lead sheath whose inner surface is at a radius R from the center of the conductor. We will designate as x the radius of any point under discussion at any time. As voltage is applied between the conductor and sheath, a very minute current will begin the flow through the insulating material. The current density naturally is greatest at the surface of the wire, decreasing, at a given applied voltage, as we approach the lead sheath. As the voltage is increased the current flowing through the insulating material increases in proportion to the applied voltage until at the surface of the wire the current density reaches the value corresponding to point A on the curve of Fig. 1. As the voltage increases, the point at which current density equivalent to A exists, moves out from the surface of the wire to a point x within the insulating material. At this moment the insulating material between a radius R and radius x is carrying a current density corresponding to a point beyond the point A on the curve and we will say for the moment that the current at the wire surface corresponds to the point B when the current density at radius x corresponds to point A. Until the current density at the surface of the wire reaches a value greater than that density corresponding to point B, there is no part of the insulating material in which the conducting path is operating with a negative voltage current characteristic. The part from radius x to radius R is still operating at a current density corresponding to points somewhere between 0 and A on the curve. The result is a stability of the insulating sheath.

At this point, if the voltage is increased, the radius at which the current density corresponds to the point A will move farther towards the sheath. The radius at which the current density corresponds to point B will move out from the conductor surface into the insulating material. We will then have in the insulating material three zone conditions:

1. The point from radius x to radius R corresponding in current density to points between O and A.
2. A distance from radius x to radius x_1 carrying current densities corresponding to the part of the curve A-B.
3. Portion of the material from radius x_1 to the conductor surface in which the current characteristic has become negative and corresponds in current density to the part of the curve beyond B.

If at this point the total voltage current characteristic of the path from the conductor to the lead sheath is still positive, the insulating material is in stable equilibrium and breakdown will not result. However, the moment the composite voltage-current coefficient of the path from the conductor to the lead sheath becomes negative, the current begins to increase rapidly and the insulating material will be destroyed by heat. This is the so-called puncture voltage and is really not a puncture voltage but is a voltage at which with the given material and spacing, the composite volt-ampere coefficient of the path from the conductor to the sheath becomes negative.

The current herein discussed is the pure conduction current such as would be produced with the application of direct-current voltage. The capacity current flowing under alternating voltage serves merely to raise the temperature of the insulating material. Due to the negative temperature resistivity coefficient of many insulating materials however, this capacity current has a very decided effect on the voltage at which the current density in the insulating material becomes great enough to destroy the material by heating. This explains certain of the discrepancies in alternating and direct-current breakdowns of insulating materials. Under this theory also the effect of time of application of voltage in the breakdown voltage becomes apparent as merely the time element of an energy function.

It is well known that gaseous conduction presents characteristics of a conductor of the class described and that this conduction is an electronic or ionic migration. In a solid insulating material the ionic motion is restricted, but there is an enormously greater supply of electrons or ions available and it seems an entirely tenable theory that this conduction in materials of this class is electronic or ionic in nature. Viewed in the light of this hypothesis, Mr. Peek's Energy Distance Theory acquires wider meanings and the ratio of $\frac{D}{d}$ equals 2.72 takes on a rather definite meaning. Our older theories of the mechanism of a breakdown of a dielectric have led to contradictory theories and ideas and the mass of data that have been accumulating does not seem to admit of explanation throughout the entire field without rather startling hypotheses and exceptions being made.

I cannot accept completely the theory of an over-stressed dielectric still carrying a certain amount of voltage gradient by some mysterious virtue of its geographical position. When we examine this phenomena under the light of the above discussed hypothesis, a certain amount of light seems to be thrown on some of our more serious problems in the insulation field. I should be very glad to have others who have been studying this field examine this hypothesis critically as I believe there is some merit in the theory and considerable evidence to support it, especially from our researches of recent periods.

F. Fernie: The writer is greatly interested in Mr. Simons' interpretation of his (the writer's) experiments.

The conception of an over-stressed dielectric still carrying its share of the voltage is new to the writer, and he is inclined to abandon the "skin-resistance" theory in favor of it. Indeed the "skin-resistance" theory was only presented for want of something better. It has been suggested as a possible explanation that the dielectric constant of an insulation may alter under an electric stress; the writer's informant having some recollection of experimental work done on porcelain in this connection, but the writer has been unable to trace it.

As Mr. Simons points out, the difficulty in forming a conclusion is the lack of data.

The only results the writer has been able to find are in a paper by Dr. Klein abstracted from the E. T. Z. in *London Electrician* dated Dec. 26th, 1913.

The following table is taken from Dr. Klein's paper, which deals with single-conductor paper cables.

	3 mm. thickness of insulation			6 mm. thickness of insulation		
	A	*B*	*C*	*D*	*E*	*F*
Area in sq. mm......	16	50	240	16	50	240
Minimum...........	20.0	20.0	20.0	35.0	30.0	50.0
Mean...............	40.3	36.6	37.2	56.5	62.0	70.3
Max................	49.3	49.0	54.0	70.0	84.0	95.0
E_1..................	20.3	15.8	14.3	18.3	16.1	14.9
E_2..................	25.4	20.8	17.6	23.5	20.6	19.0

There were apparently 60 to 80 tests made on each size cable. The figures in the first 3 columns are the breakdown values in kv.: E_1 and E_2 are the maximum stresses at breakdown calculated from O'Gormans' formula (E_1), and Deutschs modification (E_2), in kilovolts per millimetre.

The minimum stresses calculated from Klein's E_1 figures are:

A	8.8	*D*	5
B	8.9	*E*	6.3
C	10.5	*F*	7.9

These figures are inconclusive, as is to be expected, when there is such a big diversity between the maximum and minimum values found for similar samples. Still by making a selection from Klein's figures, a good case could obviously be made for a constant minimum stress. Mr. Simons attributes such diverse results to "the inherent lack of uniformity of insulating materials." The writer disagrees with this view, and regards non-uniformity as ultimately a *surface tension* effect.

Probably everyone is familiar with an experiment by which potassium permanganate solution can be filtered with blotting paper so as to emerge nearly colorless. The same effect tends to take place in the impregnation of paper cables. If the paper is wound on rather tightly so that the compound is forced to go through the paper, rather than between adjacent layers, analysis will show that the compound which reaches the inner layers of paper is different from that on the surface layers. There are then a variety of reasons for non-uniformity: (1) Tension with which the paper is lapped; this may be varied in several ways, during the lapping of one length of cable. (2) Variation in the mixing of the compound ingredients; possibility of different phases; as solution of *A* in *B*, or solution of *B* in *A*. (3) Age of the compound, *e. g.* time elapsing since mixing and amount of stirring done. As is well known spirit varnishes are particularly sensitive in these respects. (4) Temperature of compound.

It may be concluded then that paper cable making is by no means an exact science, and cable makers are unable to predict exactly what the breakdown of a particular design will be, even from the purely empirical data gained from experience.

Returning now to the minimum stress theory the writer, reasoning from the behavior of concentric electrodes, concluded that the breakdown voltage between two adjacent conductors would depend on the stress on the insulation situated midway between them. He evolved the following formula for the breakdown voltage:

$$V_{rms} = \frac{K\left(2rx + \frac{x^2}{2}\right)\log_e\left\{\frac{x+2r}{2r} + \sqrt{\left(\frac{x+2r}{2r}\right)^2 - 1}\right\}}{\sqrt{x^2 + 4rx}}$$

x is the thickness of insulation between conductors, and r is the radius of the conductors. K is a constant for any one kind of dielectric. (In one series of tests with paper $K = 39$).

This formula has given fairly accurate results with some kinds of insulation, but the writer has not made nearly enough experiments to justify him in presenting it as "Highly probable." It is given here as of possible interest in connection with Mr. Simons' paper.

L. L. Perry: Mr. Roper shows, in Fig. 12, values of "Dielectric Loss Assumed for Purposes of Calculations." His method seems an excellent one and on comparing with his assumptions the results of tests made on some recent 3-conductor cables of 400,000 cir. mils used on 13,200-volt circuit, I have thought the results might be of interest to the Institute. As will be noted by accompanying curve, Fig. 2, at temperatures above 85 deg. cent. Mr. Roper's assumed characteristics give somewhat higher values than these tests show, and so are on the safe side. At temperatures below 85 deg. the tests on all but cable *C*-2 also show lower values than in Fig. 2 of Mr. Roper's paper.

It is thought Fig. 3 which gives the average power factor for each of the four cables tested, may be of interest, as presumably this should be about the same for different sizes of conductor at the same temperature.

In these tests the power factor curves when plotted to the arithmetical-logarithmic scales, as shown, follow closely the shape of the loss curves.

The power factor at any definite temperature varies but little with a change in voltage from 7000 to 17,500 volts, the

variation above 85 deg. cent. from the average having a maximum of about 8 per cent, and below 85 deg. cent. about 25 per cent.

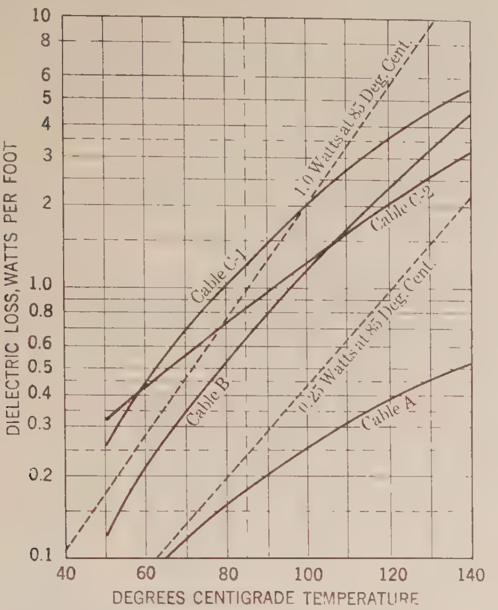

FIG. 2—DIELECTRIC LOSS FROM TESTS ON THREE MAKES OF CABLE COMPARED WITH ASSUMED LOSS

400,000 cir. mil., 3-conductor cable, 7 ft. 32 in. x 7 ft. 32 in. paper insulation—13,200 volts, 3-phase tests. Cables *C*-1 and *C*-2 of same make.

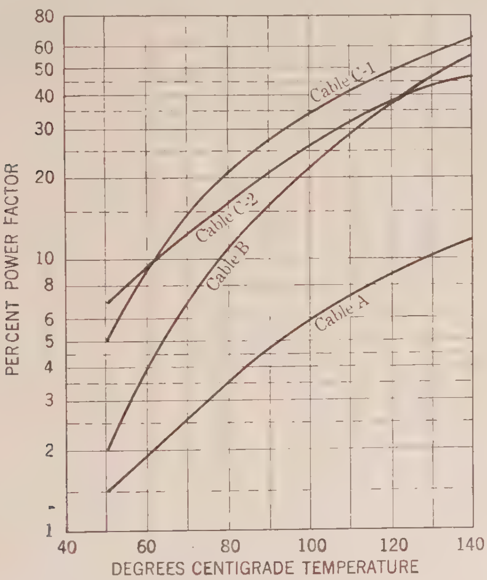

FIG. 3—AVERAGE POWER FACTOR OF DIELECTRIC LOSS IN TESTS

400,000 cir. mils., 3-conductor cable, 7 ft. 32 in. x 7 ft. 32 in. paper insulation—7000 to 17,500 volts, 3-phase tests. Three makes, *C*-1 and *C*-2 of same make. Note: Above 85 deg. cent. the tests showed a maximum variation in power factor at any temperature of only about 8 per cent from the average shown for voltages from 7000 to 17,500. For temperatures below 85 deg. cent. the maximum variation was about 25 per cent.

These are similar to the results in the power factor figures given in Clark and Shanklin's, A. I. E. E. paper of June, 1917.

W. A. Del Mar: Dynamo-electric machines and transformers are now susceptible of design with wonderful exactness. Designs made to any performance specifications would differ but little whether made by one manufacturer or another, and the performance would fulfill predictions with very little margin of error. This is because the theories of the magnetic circuit, of electromagnetic induction, and of the generation and flow of heat, are well understood and their bearing upon practical design are appreciated.

It is not so with electric cables whose insulation has seemed to us as capricious, in its behavior, as the magnetic circuit must have seemed to dynamo designers in the days of the long-pole Edison dynamos.

It is hoped that this symposium will be the starting point for research which will be as epoch-making as Hopkinson's work on the magnetic circuit, which put dynamo design upon its present basis of exactness. The papers which have been presented do not record any startling discoveries, but taken in the aggregate, they show that cable engineers are alive to the problems before them and that both manufacturers and operators are closing in upon some basic facts and devising ingenious theories that may lead eventually to the solution of the major problems.

While not part of this symposium, Dr. K. W. Wagner's recent Institute paper should be studied in connection with the present group.

It is interesting to note that two papers are devoted to theories of dielectric loss; that they are both based upon imaginary microscopic views of the insulation, which reveal a heterogeneous structure, and that both blame the dielectric loss upon this heterogeneity. The two theories differ in that in one, moisture particles are held to be the culprits, whereas in the other, the impregnating compound is blamed.

There is no doubt about the fact that moisture was to blame for the high dielectric loss of many of the cables of years ago. These cables were not thoroughly dried, both the paper and the oil containing moisture in considerable quantities. The power factors of such cables, when plotted against oil resistivities, do not lie anywhere near the theoretical curve in Fig. 3 of our paper. For example, an oil resistivity of 0.5×10^{12} ohm-cm. corresponds to a theoretical power factor of 5 per cent at 85 deg. cent. A cable with about 2 per cent moisture, as derived by vacuum dessication at 130 deg. will have a power factor of about 18 per cent. The water, in such a case, is the principal factor determining dielectric loss. In our paper we expressly state that in applying the theory it is assumed that practically no moisture is present, as a very small proportion will have a greater effect than even a fairly large reduction in the resistivity of the oil or cellulose. Our theory is intended to explain that element of the dielectric loss which occurs in a well-dried cable, and it has been found to be so reliable, as a working guide, that we can confidently state the power factor of every length of cable made in the factory merely by making resistivity tests of the oil. Since the wr ting of the paper, an experimental point has been obtained for Fig. 3 corresponding to a resistivity of 6×10^{12} ohm-cm. The theoretical value of the corresponding power factor was 2.04 per cent; the experimental value was 2.1 per cent. We are pleased to note that Mr. Shanklin's views support our own.

We may thus claim to be able to scientifically design cables for power factors. Having accomplished this, our next step was to try to design for dielectric strength. The first obstacle to be encountered was the lack of formulas to express a relation between the dielectric strength of the insulation and the breakdown voltage of a cable. A fundamental difficulty stood in the way; the apparent dielectric strength of flat samples varied with their area and thickness. Dr. Wagner came to the rescue with his mosaic electrodes, which enabled true dielectric strength to be measured. Knowing the true dielectric strength of the insulation how can the breakdown voltage of a cable be calculated? Mr. Peek has given a working solution in the case of single-conductor cables which may be expressed by the formula

$$E = 2.3\, S\,(1 + 1.1\sqrt{r})\log_{10}\frac{R}{r}$$

Where E = breakdown tension, kv.
S = dielectric strength, kv./cm.
R = outer radius of insulation, cm.
r = inner radius of insulation, cm.

In the case of triplex sector cables which we have tested

$E = 0.9$ St

Where E = breakdown voltage between conductors, kv.
S = dielectric strength, kv./cm.
t = thickness of insulation between conductors, cm.

With the same kind of insulation, these two formulas give about the same value of S. Our own experiments confirm Mr. Peek's formula far more strikingly than the experiments cited by him. For example, twelve single-conductor cables having $r = 1.04$ cm. and $R = 2.67$ cm. broke down at an average of 200 kv. the same value being attained at 25 deg. and 85 deg. cent. Mr. Peek's formula also gave 200 kv.

Some experimental data published by Dr. Klein in the E. T. Z. and abstracted in the *London Electrician* of Dec. 26, 1913, show a much more uniform stress at the energy distance suggested by Mr. Peek than either at the conductor surface or the sheath surface.

Equipped with these formulas the next step was to find the factors upon which the value of the dielectric strength S depends.

The ion-baffle theory was applied in the following way. The dielectric strength of impregnated paper insulation in a cable may be expressed by the following formula:

$$S = S_o B F$$

Where S = dielectric strength of impregnated paper in cable,
S_o = dielectric strength of oil,
B = factor expressing baffling effect of paper,
F = factor expressing variations other than those affecting the factor B. (Principally factors affecting the formation of vapor pockets.)

The range of variation of the above quantities with ordinary commercial materials and processes is about as follows:

S_o	20 — 33
B	2.0 — 5.0
F	0.5 — 1.0

Hence, the maximum and minimum values of S would be 165 and 20 respectively, but the combination required to produce so low a dielectric strength as 20 kv./cm. would be rare. Most commercial cables run between 50 and 100 kv./cm. The stress, in this case, is assumed to be calculated by the formulas given above.

By analyzing the causes of the variation in each of these factors, it has been found possible to raise their values and so greatly increase the dielectric strength of the insulation.

I am pleased to note Mr. Shanklin's general concurrence with our theory of dielectric loss and with our conception of ionic migration in oil. While he agrees that this conception serves to explain both ordinary conduction and dielectric failure under long applications of tension, he takes exception to applying it to explain failures under short applications of tension. He cites two reasons for this point of view. The first is that cables of low dielectric loss and therefore of low ion mobility, often breakdown at low voltages on short period tests, and the second is that impregnating compound of high resistivity and therefore also of low ion mobility, often has very low dielectric strength. He argues from this that as low ion mobility does not result in high dielectric strength, the failure of insulation cannot be due to the mobilization of ions.

There is a general answer to both of these reasons, namely, that the kind of ionic mobility that constitutes the conductivity of the insulation is obviously the average mobility, whereas, that which would lead to sudden dielectric failure would be a local maximum mobility. Such a local maximum is not necessarily proportional to the average, especially in dielectrics of such complex nature as either impregnated paper or impregnating compound. There is also a special answer to Mr. Shanklin's first objection, namely, that the ionic mobility of the impregnating compound only affects the factor S_o in the above formula, whereas, the low breakdown voltage of the cables may have been due to low values of the factor B or F.

Mr. Shanklin has called our attention to a very important element in cable failure, namely, the establishment of local high-frequency surges at vapor pockets. I am inclined to believe that practically every cable that fails on five-minute test, fails from this cause, but I do not believe that a failure will start at either the conductor or the sheath because these large masses of metal would prevent any sudden local temperature rise in the insulation adjacent to them. It is generally the heating due to these surges which creates the local maxima of ion mobility referred to above.

A curious fallacy has obsessed cable makers for many years, namely, that the thickness (*i. e.* viscosity) of the compound should be so great that it will not flow in the cable. In the attempt to follow this theory, compounds have been made of heavy mineral oils thickened with resin. This theory would have been satisfactory if cables were stationary apparatus, but it neglected the fact that cables have to be bent in manufacturing, testing, installing and splicing. When a cable is bent, it is contracted on the inside of the bend and expanded on the outside. If the oil is too viscous, it will not flow from the inside to the outside of the bend, and therefore, the cable will be dielectrically weak due to vapor pockets on the outside of the bends. Cables made with oil of a viscosity properly adjusted to the paper tightness, break down at the same voltage hot or cold.

K. W. Wagner's interesting paper delivered at a Chicago meeting of the Institute this year should be read in connection with Mr. Roper's paper, as both arrive at similar conclusions from entirely different avenues of approach. In this paper, the theory is advanced that solid dielectrics fail due to their negative temperature coefficients of resistivity. If heat is generated in a filament of insulation more rapidly than it can be dissipated, the resistivity will fall off cumulatively until it is so low that the current becomes high enough to burn the filament. According to this theory, it is the slope of the resistivity-temperature curve and not the actual value of the resistivity which determines dielectric strength.

Prof. Scott has told us that a successful 25,000-volt cable was installed some twenty years ago and that we are still practically at the same stage. The cable he was thinking about was installed twenty-two years ago, and practically no important progress in cable making occurred in twenty of those twenty-two years. The advances recorded at this meeting are the product of the last two or three years and are due entirely to the progressive spirit of a few manufacturers and to the untiring efforts of a few cable users.

D. M. Simons: I believe that possibly one of the most important developments of the discussion is the emphasis laid on the negative temperature coefficient of insulation resistance by Dr. Steinmetz, Mr. Peaslee and Mr. Del Mar's quotation from Mr. K. W. Wagner. Mr. Peaslee's application of this idea to the case of concentric electrodes in terms of insulation resistance and the current density, instead of the more usual method of voltage and stress, is most interesting. I believe that even if the negative temperature coefficient is not the complete answer, it will undoubtedly have to be included in any future theory of cable breakdowns.

While my paper is not really a criticism of Mr. Fernie's article, but merely an attempt to explain one section of his data by a different theory and to emphasize the lack of true constancy of his experimentally determined minimum stresses, I was especially glad in reading the final proof of the discussion to find that he had had an opportunity to comment in writing. His remarks have been read with pleasure. Mr. Fernie's formula for the breakdown strength of a multi-conductor cable is interesting. During the preparation of this paper, the writer also developed a formula for the breakdown voltage of a three-conductor cable on the same theory as that outlined for a single-conductor cable, based on the ratio of diameter under lead sheath to conductor diameter giving the minimum value of maximum stress as calculated for triplex cables in the paper of which he was co-author in the January 1921 JOURNAL. This, however,

was not included in the present paper, since the theory did not seem to be vindicated sufficiently for the case of single-conductor cables.

Many theories have been proposed. The true solution must exist, but it undoubtedly cannot be determined until the amount of available experimental data is vastly greater than at present.

J. E. Shrader: I wish to say just one word in regard to the potential gradient and the formation of corona, which, as Prof. Whitehead has said, is rather a difficult one to calculate. I do not know with our present state of knowledge, that we could calculate the potential gradient through the range which is used.

Dr. Whitehead also spoke of the abruptness with which the power factor changes in some cases and not in others. That there is a very abrupt change in some cases, I attribute to the fact that there are more uniform layers of gas. With the thinner layers it is almost impossible to have a uniform thickness of gas layer, in which case there is a gradual variation of the power factor.

I think, as Prof. Karapetoff has said, that we ought not to be afraid to tackle these problems on the ionization theory, and modern theories which are being produced. I think it is going to be a matter of getting at the fundamental data and coordinating it with modern theory which will solve all of our engineering problems.

C. F. Hanson: Referring to the Del Mar-Hanson paper, the imperfection angle is the angle by which the current falls short of leading the applied voltage by 90 deg. In a perfect dielectric the current would lead the applied voltage by 90 deg.

Other data on the relation of the power factor of impregnated paper and the resistivity of the impregnating compound have been obtained since Fig. 3 in the paper was produced. In Fig. 3 the points shown from actual measurements were obtained at 85 deg. cent. We have now obtained additional points at 70, 80 and 90 deg. cent. These points, in addition to the 85 degree points, are shown in Fig. 4 of this discussion. The points all lie very close to one curve.

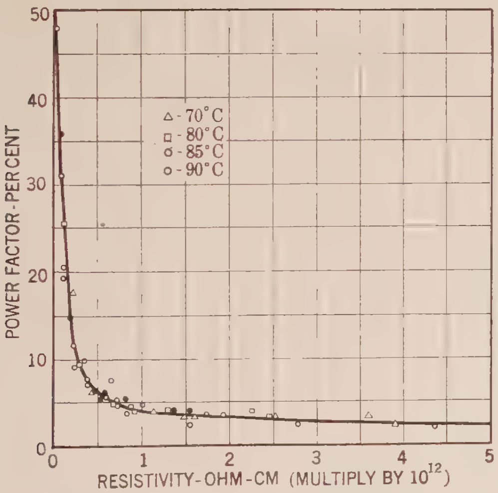

Fig. 4—Relation of Power Factor of Impregnated Paper and Resistivity of Impregnating Compound at Temperatures 70 to 90 Deg. Cent.

The use of the curve may be illustrated best by an example. Suppose the resistivity of a compound at the various temperatures is as follows:

Temp. deg. cent.	70	80	85	90
Resistivity (ohm-cm.)	2.5	1.3	1.0	0.80×10^{12}

From the curve we obtain the power factor of paper impregnated with the above compound for the given temperatures. Of course the paper has to be thoroughly dried and impregated. The power factors obtained are as follows:

Temp. deg. cent.	70	80	85	90
Power Factor (per cent)	3.0	3.7	4.0	4.5

The curve does not hold good for 60 deg. cent. or less.

Mr. Shrader has contributed some valuable information in his paper. His curves marked "1" in his Figs. 3 and 12 are very interesting. They show that manila paper saturated with petroleum jelly has a smaller imperfection angle than white India mica at stresses up to 60 kv. per cm. Ordinarily we do not think of an impregnated paper having any electric qualities superior to mica.

Referring to his Fig. 14, Mr. Shrader discusses the difficulty encountered in obtaining consistent values of power factor and potential gradient in the ionization region. We have found that one reason for this difficulty is that when ionization is reached the deflection of the wattmeter is a function of time of the application of voltage. Perhaps a part of the difficulty could be

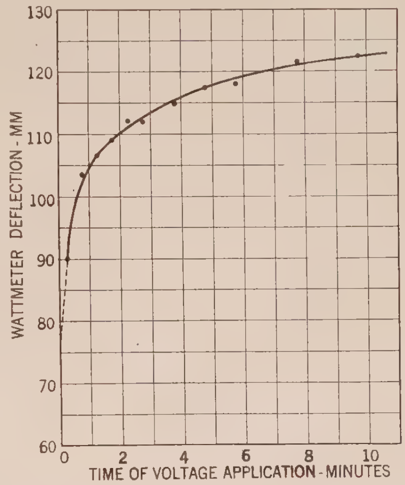

Fig. 5—The Effect of Time of Voltage Application on the Measurement of Dielectric Loss when Ionization is Present.

overcome by taking readings after a definite period of application of voltage. The length of the period would have to be determined by experiment. It is impossible to obtain readings at the moment the voltage is applied because, even though a wattmeter is aperiodic, there is a time lag in the deflection. I submit a curve, Fig. 5, showing variations of deflections with the time of application of voltage. The readings were taken on impregnated paper at 30 kv. Ionization started at about 24 kv.

The first point on the curve was taken 15 seconds after the full potential of 30 kv. was applied to the dielectric. We could not obtain a reading sooner because it took 15 seconds for the wattmeter to come to a steady deflection. The reading was 90 mm. If we could have read the wattmeter the moment full potential was applied we would, perhaps, have obtained a reading of about 75 mm. as indicated by the curve. The time for building up the voltage was about 15 seconds. The curve shows the importance of allowing a definite fixed period for building up the voltage and a fixed period between the time when full voltage is obtained and the time when the wattmeter is read.

Mr. Shrader has calculated the effective a-c. resistance both from the point of view of a fictitious resistance in series with a perfect condenser and also in multiple with the condenser. If the resistance in series with the condenser be designated as r and the resistance in multiple as R, the power factor may then be expressed as follows:

$$\cos\theta = \sqrt{r/R} \tag{1}$$

or

$$\sin\psi = \sqrt{r/R} \tag{2}$$

where ψ is the imperfection angle and is equal to $(\pi/2 - \theta)$.

The above equation is useful in checking the calculations of r and R which have been obtained from

$$r = W/I^2 \tag{3}$$

and

$$R = E^2/W \tag{4}$$

The power factor is ordinarily obtained from the equation

$$\cos\theta \frac{W}{E\,I} \tag{5}$$

Values obtained from equations (3), (4) and (5) should satisfy equation (1).

D. W. Roper: Mr. Fisher has apparently misread or misinterpreted the statements in my paper regarding the relative merits of foreign and American cables. It is my impression, based upon the results of a great many dielectric loss measurements, made for the company with which I am connected, and comparing these with the dielectric loss figures which have been furnished me by foreign engineers and manufacturers, and also by the figures quoted by Mr. Welbourn this morning, that on the question of dielectric loss the American manufacturers are not at any disadvantage as compared with the foreign manufacturers.

The figures obtained appear to indicate that the dielectric losses of the foreign cables are about on a par with the best American practise, and in fact some of the figures obtained from a few samples of American manufacture are lower than any I have been able to obtain on foreign cables, the only exception to that statement being one very special case of a foreign cable made with a hollow conductor and impregnated with a thin liquid insulation of the nature of transformer oil rather than a grease, of the nature of petrolatum, and even in that case, the loss was not materially below the best records of tests published in this country.

Mr. Atkinson made some comments on the bending test called for in the English specifications, and in the National Electric Light Association specifications. He did not mention, however, that the English specifications, although they are more severe, call for three cycles instead of two, as is the case with the American specification, but they do not permit of any tearing of the insulation, whereas the National Electric Light Association's specifications permit a maximum of two layers being torn at any one point.

As a matter of practical experience, we know that with this limitation of two torn papers at any one point, there can be scattered throughout the cable a great many other tears of the insulation, following the bending test, without there being two at any one point, and this is a radical point of difference between the two specifications.

We have found, although we have made several hundred bending tests in the last four years, that only in cases where the insulation is very poor in quality, do we find that the bending test shows any difference whatever between the test at room temperature and the test at minus 10 deg. cent. The curves shown in the paper, on bending tests, quality of paper, etc., shows that in most cases no tearing whatever results, even at the minus 10 deg. cent. test.

There is one point, however, in which the English have an advantage over the American manufacturers, and which is not brought out in this paper, and which was contributed as a part of the report of the Committee on Transmission and Distribution.

The American cable manufacturers were all given an opportunity to present their ideas regarding the thickness of insulation they would recommend for various voltages, and we also had the thicknesses published by the British Engineering Standards Association. The thicknesses recommended by the British are in general below the thicknesses recommended by the American manufacturers, and some of the latter recommend up to 25 per cent more. The English practise, however, appears, as near as we can discover from correspondence with their engineers, and from some of our engineers, who have been to England,—to use somewhat less insulation than is specified by the British Engineering Standards Association. The thicknesses which the Commonwealth Edison Company have been using in the last year or two are about the same as the British Engineering Standards Association, although we have been accused of being somewhat radical on that point. It was, therefore, of great interest to learn recently, that one of the English companies, that has been operating 20,000-volt cables for a number of years, and has had considerable experience, has, upon the basis of their own experience, and on the advice of their consulting engineers, reduced the thickness of insulation by 25 per cent on these 20,000-volt cables, so that the thickness of insulation which will be used on 20,000-volt cables, is only a trifle more than the Commonwealth Edison Company is using for 12,000-volt cables.

It is to be hoped that the investigations which the American cable manufacturers have started, as evidenced by the series of papers this morning, will continue until they are at least on a parity with the foreign manufacturers in this respect.

It is also of interest to note that apparently some of the data which have been presented this morning have resulted primarily in further investigations into the properties of cables and into the properties and desirable features to be incorporated in condensers for insulation with 60-cycle systems for improving the power factor. Private information indicates that more than one manufacturing company has a larger engineering staff investigating this subject, which is not yet in serious commercial production, than they have investigating the properties of paper insulated cables.

We are perfectly willing that the manufacturers should get information in that way or any other way, which will help them in the design of their cables.

It is also interesting to note the serious advances made in this country in the direction of dielectric losses. In looking over the guarantees received in the last few years, from the American manufacturers,—and we give them all a chance when we ask for bids—it was noticed that the maximum dielectric losses on a certain size of cable last year at a temperature of 80 deg. cent., was double the maximum figures we received this year at the same temperature and same size of cable.

It would have been interesting if Mr. Welbourn has given his dielectric loss data in power factor rather than watts, as, without knowing the size of the cable, it is difficult to compare it exactly with the other data that are available.

The calculations to determine the maximum permissible current on various sizes and voltages of cables were based on the average duct radiation as given in the Clark and Shanklin paper of 1919, and now Mr. Shanklin in a measure discredits these data, or at least casts a doubt on its accuracy for this purpose. This serves to emphasize the importance of securing more fundamental data. To obtain the data from cables in commercial operation appears to be a very difficult task due to the variations in load on the cable, but it would be of great value if some investigator could surmount the difficulties and devise a method which the operating companies could use for measuring the radiation constant of their conduits. In spite of the inaccuracies of the fundamental data as pointed out by Mr. Shanklin, we do find that for the conditions in Chicago, the figures obtained from these calculations are a sufficient guide to enable us to determine within less than ten per cent the amount of load that can be safely carried on our cables without being subject to dielectric loss failures.

W. I. Middleton, C. L. Dawes, E. W. Davis: In view of the present day tendency to operate cables at higher voltages without increasing the walls of insulation, it is of vital importance to engineers to know the actual rather than the theoretical stresses within a cable. A mathematical formula which cannot be checked experimentally should not be accepted as standard for calculating such stresses. If the formula published by Mr.

Atkinson in the PROCEEDINGS of the A. I. E. E. in 1919 has been "thoroughly substantiated" as Mr. Simons says, it would be of inestimable value to engineers to have the figures published.

The design of three-conductor cables depends largely upon insulation constants obtained from tests on single-conductor cables. The relation between breakdown stresses in single and three-conductor cables is necessary to assure the proper design of the three-conductor cable.

We do not believe that the rupturing stresses in three-conductor cables are materially lower than for single-conductor cables, especially if such cables be well made. From the data of breakdown tests made by us, the stresses calculated by the old method are much more in accordance with our belief than stresses calculated by the new method.

In the discussion, Mr. N. L. Morgan has remarked that he does not understand how insulation can be overstressed and at the same time not destroyed.

The stressing of insulation is analogous to stresses and strains in the testing of mechanical materials. In the latter case, if the test is not carried beyond the elastic limit, the material recovers immediately after the test load is removed. If the elastic limit has been passed, the material never completely recovers, even though the material is not destroyed.

In a paper "Voltage Testing of Cables" by Middleton and Dawes read before the Institute in June 1914, the matter of overstressing cable insulation was discussed. It was shown that it is possible to apply such severe voltage tests to cables that they do not recover their original insulating properties. The following table shows the results of stress on some rubber insulated cables:

MEGOHMS PER 1000 FEET

Test No.	Length tested feet	Initial M. O. before voltage	Immediately after 2500 V 1 min.	Immediately after 5000 V 1 min.	2 Hours after 5000 V 1 min.	Immediately after 5000 V 5 min.	2 Hours after 5000 V 5 min.
1	1562	14,500	14,500	7,500	11,500		
2	1547	22,000	22,000	16,000	18,000		
3	3150	7,500	7,500	6,000	7,000	5000	5000
4	1740	15,000	15,000	6,500	10,000	750	2500
5	2402	15,000	15,000	7,500	10,000	2500	3500

The insulation resistance in tests 1 and 2 were considerably affected by the 5000-volt, one-minute test, but practically recovered after 2 hours. Test 3 showed the least effect of the 5000-volt, one minute test, while 4 and 5 showed rather slow recovery. An additional 5000-volt, 5-minute test apparently caused permanent injury to 3, 4 and 5, as they showed very little recovery after 2 hours.

In no case was the insulation ruptured but in 3, 4 and 5 it was most certainly overstressed.

We quite agree with Professor Karapetoff that the effects on the dielectric strength of the various elements entering into the composition of a dielectric should each be analyzed separately, in order to understand more thoroughly the nature of voltage breakdown. The papers of Messrs. Del Mar & Hanson, Du Bois and Schrader are analytical in this sense and their data and conclusions give in a degree, quantitative effects of moisture, air spaces, etc., on the ultimate properties of the dielectrics.

On the other hand whether or not the results of such investigation are correct can only be ascertained by data obtained from the finished cable, both in the factory and under operating conditions as are given in Mr. Roper's paper. Therefore even though data do not involve the individual effect of each element of the dielectric, they are nevertheless valuable.

Professor Karapetoff mentions the fact that the stresses in dielectrics, which are stressed beyond the elastic limit should not be calculated with constants derived for the material when not so stressed. Our investigations on the special cable, the results of which are shown in Fig. 5, was undertaken to determine such effects. The average effect for insulation in the interior of the cable which was overstressed was only of the order of 5 per cent at the instant of break down, a negligible error as compared with deviations ordinarily obtained with dielectric tests. This cable was purposely made with an inferior grade of rubber compound in order to exaggerate the effect of overstressing. A high-grade compound would have shown a much smaller change in permittivity. This combined with other measurements that we have made, leads us to believe that the change of permittivity of the ordinary rubber compounds under stress can be neglected when calculating potential gradients. We would expect greater changes in paper cables, as the low viscosity of the filler permits the components having the greater permittivities to seek positions in those portions of the electrostatic field which have the greater intensities. We have as yet made no attempt to measure this change with paper cables.

The pyro-electric theory of dielectric destruction presented by Dr. Steinmetz and Mr. Peaslee offers a very plausible explanation of dielectric rupture. The phenomenon of the volt-ampere characteristic of the dielectric attaining a negative slope, and the current running away must occur in a very short interval of time as otherwise the comparatively small amount of energy involved would be unable to raise the temperature to the values necessary for this phenomenon to occur, for the heat would be conducted away too rapidly.

It will be interesting to see if further investigations substantiate this theory.

We are very interested in Mr. Peek's energy-distance theory of the breakdown of gaseous dielectrics as applied to solid dielectrics. Accordingly we have attempted to evaluate constants for the series of tests given in our Tables I, II and III inclusive.

In Table I, we find that equation $g_v = M\left(1 + \frac{K}{\sqrt{r}}\right)$ gives consistent results as shown in the following tabulation.

M was found to be 116 and $K = 0.345$.

Size cond. A.W.G.	r Cm.	$0.345\sqrt{r}$	R_1 Radius to point of constant stress. cm	R Outside radius cm.	R_1/R	Stress from curve for Table I similar to curves for Table II shown in Fig. 10. Values of R_1/R same as in preceding column
24 Sol	0.0255	0.0550	0.080	0.476	0.168	300 Volts per mil
20	0.0407	0.0696	0.1103	0.476	0.232	270
14	0.0826	0.0992	0.1818	0.476	0.382	270
. .	0.1140	0.1165	0.2305	0.476	0.485	270
8	0.1625	0.1390	0.3015	0.476	0.634	300
6	0.206	0.1435	0.3495	0.476	0.734	290
5	0.236	0.1535	0.3895	0.476	0.818	295
2	0.328	0.1975	0.5255	0.476	1.104	340
2 strd.	0.330	0.1980	0.528	0.476	1.11	410

It will be noted that except in the case of the two solid and two stranded conductors, the stress was practically constant at a radius R_1 from the center of the conductor.

We were unable to find any values of M and K that would satisfy Tables II and III. In fact in some instances the constant K became negative. Therefore, it would seem to us it has not yet been proved that this theory is applicable to all breakdown of solid dielectrics. Perhaps if the time of test were made very long, hence give the ions greater time to bombard the dielectric, the breakdown voltages might more nearly agree with these energy-distance equations.

THE TWO-STAGE CURRENT TRANSFORMER*

(Brooks and Holtz), Niagara Falls, Ontario, June 27, 1922

James R. Craighead: There are in addition to those outlined in this paper, several other methods of making phase angle correction in current transformers. The simplest is the use of a non-inductive shunt placed across the primary winding or across the secondary winding, which subtracts a certain amount of current either from the primary or the secondary side of the transformer. This current is in a phase position which is such that it tends to restore the remainder of the secondary current to the phase position of the primary current, and by so doing can diminish to some extent the usual leading (or positive) phase angle of the current transformer. Inductive reactance may be substituted for the non-inductive shunt where the phase angle is negative.

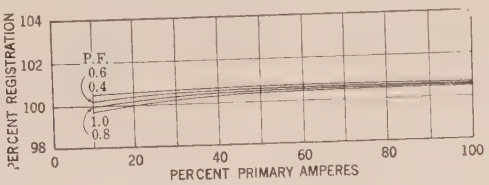

Fig. 1—Current Transformer for Metering Service—Accuracy at 60 Cycles

Burden of 1.8 ohms resistance (45 voltamperes)

An extension of this method is the use of a separate winding on the core of the current transformer, which gives an opportunity of using other voltages than the voltage generated at the secondary terminals. This allows the use of condensance, reactance and resistance; and by using these three the sub-division of the current can be made so that the net current going through the meter for any given point can be brought more exactly into phase apposition. Both these methods produce a correct phase angle under only one condition, and change in current, frequency or secondary burden is usually accompanied by change in phase angle.

Consequently, this form also does not give a continuous or complete correction.

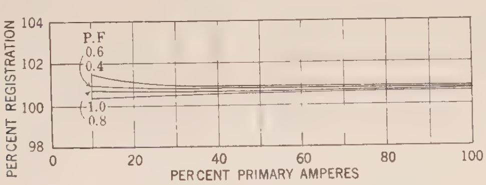

Fig. 2—Current Transformer for Metering Service—Accuracy at 60 Cycles

Burden of one watthour meter and leads (0,15 ohm resistance, 3.75 voltamperes)

A third method requires the use of two current transformers. A main current transformer has the standard connection, with its primary in the primary line, and its secondary connected to the meter or other burden. An auxiliary current transformer is placed with its primary either in the primary line or the secondary line, and it has a ratio very different from the ratio of the first transformer.

This second transformer produces a very small current, roughly sufficient to produce a corrective result if applied either across the primary terminals of the main current transformer, or across the terminals of the burden. A combination can be made to produce a result which is somewhat better than a simple point correction, by selecting main and auxiliary transformer so that their characteristics tend to offset errors through same range. As the auxiliary transformer has a comparatively large number of turns, more accurate correction of ratio may be made than with a transformer of standard type. Full correction can be obtained under only one condition, as in the preceding method.

The method proposed by Mr. Brooks, while resembling the previous method in the use of two transformers, is distinctly different in principle. If the auxiliary secondary, which I prefer to call the tertiary is disconnected, the transformer consists of a core subdivided into two parts, with a common primary and secondary on both parts, the secondary being connected to an external burden. If then we connect the tertiary to a burden of low impedance, the corrective current drawn reduces the flux in the auxiliary core. This increases the impedance of the secondary circuit and increases the voltage developed in the

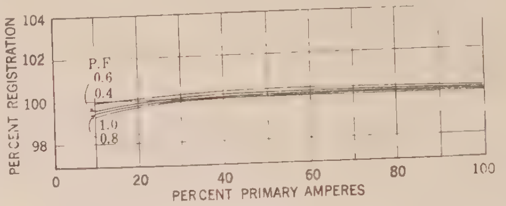

Fig. 3—Current Transformer for Metering Service—Accuracy at 60 Cycles

Burden of 0.97 ohm resistance, 4.03 milli henries inductance (45 voltamperes at 0.54 power factor at 5 amperes 60 cycles)

secondary by the main core, and consequently the flux in the main core and its exciting current. The error in the total secondary circuit is therefore increased, and we get a subdivision into two circuits, one whose accuracy has been largely increased by the redistribution of the flux, and the other whose accuracy has been decreased by the same cause. The auxiliary core is really excited by the difference between the primary and secondary currents as a true primary current, and the tertiary winding tends to deliver a proportionate current. Since this difference is the error in transformation of the main transformer, the corrective current changes in proportion to the need for correction. Consequently moderate changes in frequency, secondary burden

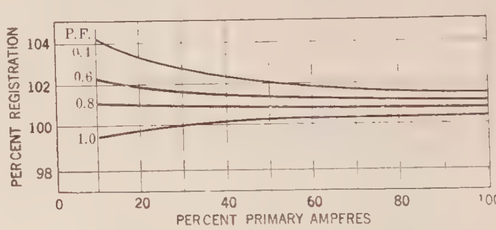

Fig. 4—Current Transformer for Metering Service—Accuracy at 25 Cycles

Burden of 1.8 ohms resistance (45 voltamperes)

or primary current make only very small changes in accuracy. From this the Brooks plan is evidently applicable where it s desirable to obtain high accuracy over a very small portion ofi the secondary burden, as a watthour meter. Where the purpose is to obtain better general accuracy on a large burden, such as curve drawing instruments, balanced relays, etc., the method is not applicable.

Mr. Brooks has furnished curves showing the performance of an ordinary commercial type of transformer for comparison with his device. These results are not as good as may be obtained with the better grade of commercial transformers.

Figs. 1 to 6 show the accuracy of a meter (neglecting its internal error) operated from a current transformer of good standard type at power factors from unity to 0.4 lagging, with various secondary burdens and frequency.

*A. I. E. E. Journal, 1922, Vol. XLI, June, p. 389.

The first three show operation at 60 cycles, with burdens of (Fig. 1) 1.8 ohms non-inductive resistance, or 45 volt-amperes, at 5 amperes and 60 cycles; (Fig. 2) 0.15 ohms resistance or 3.75 volt-amperes (practically a watthour meter with its leads); and (Fig. 3) 0.97 ohms resistance with 4.03 milli-henries inductance or about 45 volt-amperes at 0.45 power factor. This last is the highest burden recommended for use with the transformer when a watthour-meter is included. The results show errors due to the transformer of less than 1 per cent, as compared with much larger errors shown by the transformer used as a comparison by the authors of the paper.

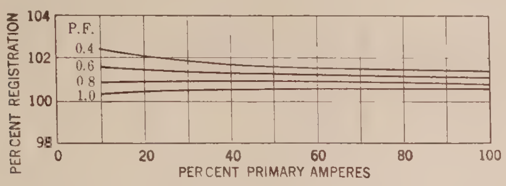

Fig. 5—Current Transformer for Metering Service—Accuracy at 25 Cycles

Burden of one watthour meter and leads (0.15 ohm resistance 3.75 voltamperes)

The next three figures show similar data for the same transformer and burdens at 25 cycles. In Fig. 4 is shown the effect of a non-inductive burden of 1.8 ohms—which is rare in metering practise—on the accuracy for comparison with Fig. 1. Fig. 5 shows the accuracy with burden of watthour meter and leads corresponding to Fig. 2, and Fig. 6 the accuracy with the full-rated burden for this service, corresponding to Fig. 3.

With the last condition, the maximum error is again reduced to close to one per cent, while the more severe condition shown in Fig. 4 causes a maximum error of over 4 per cent, approaching the amount shown in Mr. Brooks' example at 60 cycles. This, however, is a burden greater than is recommended for watthour meters to work with the transformer.

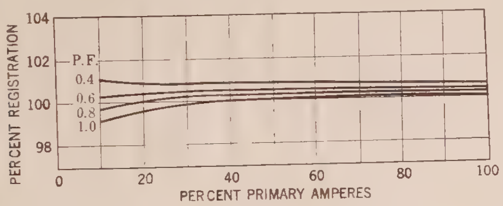

Fig. 6—Current Transformer for Metering Service—Accuracy at 25 Cycles

Burden of 0.97 ohms resistance, 4.03 milli henries inductance, (45 volt-amperes at 0.54 power factor at 5 amperes 60 cycles)

A study of the 25-cycle results shows that the average error through the ranges selected is in each case in the same direction. It may therefore be partly offset by adjustment of the potential transformer burden or of the watthour meter itself.

Perry A. Borden: In developing the two-stage current transformer, Mr. Brooks has eliminated what has been probably the worst feature in a-c. metering. Heretofore, about the only comfort we had lay in the possibility of the current transformer errors being to some degree compensated for by those of the voltage transformers. But this, even if true for one condition of the load could not be universally so.

While the two-stage principle, as applied to transformers of an inherently compact design and of high ampere-turns means a close approach to perfection, it would seem that its greatest application would lie in the field of air-insulated transformers for high-voltage work, and for bushing type transformers where the primary is, of necessity, limited to a single turn.

A limiting factor in the use of the two-stage transformer would appear to be introduced by the necessity of duplicating the secondary wiring both internally and externally to the meter. On large systems, where each installation is subject to the supervision of a trained meter-man, this would mean little difficulty; but on small utilities where the metering installations are made by a wireman with no court of appeal but the manufacturer's blueprint, the probability of error in the meter wiring would be double what it is now; and I think those who have had experience with meters installed by non-technical help, will agree that this is no small factor.

I should like to ask Mr. Brooks if he has made any studies or carried on experiments in the use of this transformer without the refinement of the extra winding in the meter. It would seem that the commendable features of the principle would be sacrificed but little by paralleling the secondary and the auxiliary windings in the meter, or even at the terminals of the transformer. If this could be done, the only objection to the device,—that of duplicate current circuits—would be at once removed.

F. C. Holtz: In reply to Mr. Craighead's remarks we might add that it was not our intention to show in this paper the characteristics of the best transformers to be had. We did, however, choose a transformer of good average characteristics—a type which represents a fair average of those in service today.

I should also like to inquire of Mr. Craighead the weight of the transformer whose characteristics were shown on the screen.

J. R. Craighead: It varies from 20 pounds up to about 1500. It is an average curve of the total amount of transformer.

F. C. Holtz: The two-stage current transformer can be made extremely light in weight. For example, we have made transformers of 200 amperes capacity with one turn, weighing approximately 13 pounds. This being the total weight of a transformer for 13,200-volt circuits.

The two-stage principle becomes particularly applicable for high voltages where it is necessary to obtain great separation between primary and secondary, and where the simple transformer cannot maintain the high standards of metering accuracy.

In reply to Mr. Borden's discussion, I should like to bring in an endorsement of his suggestion that an important application is that of the one-turn-primary current transformer. Where metering is done close to the generator bus, it is often found that the multiple turn transformer cannot withstand the effect of short circuits and a compromise is reached between the operating and meter departments through the installation of single-turn-primary current transformers. While such transformers do readily withstand the effects of short circuits, they very often fail to give satisfactory results in metering. This is particularly true of transformers of 200 amperes capacity and lower. Such transformers often show over 5 per cent variation in ratio from 10 per cent load to 100 per cent and have phase angles as high as 6. degrees on light loads. It is possible through the application of the two stage principle to build current transformers of the one turn primary type, which in addition to possessing the feature of indestructibility, have good electrical characteristics at low secondary burdens, such as for example, a meter element and .1 ohm resistance. Transformers of this type have been constructed which maintain correct ratio to within .3 per cent from 10 per cent to 100 per cent load, and whose phase angle is less than 10 minutes over the same range of load.

H. B. Brooks: Referring to Mr. Craighead's statement that the two-stage transformer is applicable only where it is desirable to obtain high accuracy over a very small portion of the secondary burden, we consider that it is only a question of design to obtain high accuracy over a large burden. In general, it is not necessary to do this, except in the case of watthour meters, for errors of even several per cent are not serious where the object is to obtain data as a guide in operating the plant. Of course, if the large burden introduces a relatively large mutual inductance between the main and auxiliary secondary circuits, corrective measures may have to be employed. The simplest is the use of an external mutual inductance of equal magnitude

and opposite sign, by which the error in question may be reduced to zero.

Tests by Mr. Holtz show that in two-stage transformers having at least 800 ampere-turns the effective ratio and phase angle are not impaired by the introduction into the auxiliary secondary of burdens approximately equal to that of a graphic wattmeter and only to a slight extent by introducing a graphic ammeter or relay. He has made tests of an 800-ampere-turn two-stage current transformer and has found that a considerable burden can be introduced into the auxiliary secondary circuit without greatly affecting either ratio or phase angle, and that even at 25 cycles the results are quite satisfactory and superior to those obtainable in ordinary current transformers of the highest performance commercially obtainable.

While the use of duplicate current circuits is a drawback as Mr. Borden suggests, it is not nearly so serious as might at first appear. If the principal secondary circuit of a two-stage current transformer be opened under load, the auxiliary secondary winding will supply a current nearly equal to the desired total secondary current. This fact gives a means by which even an unskilled man may check the correctness of the connections of the auxiliary secondary coil, as follows. Assume that a three-phase watthour meter is to be operated by two two-stage current transformers. First the auxiliary secondary coils are disregarded, and it is immaterial whether their terminals are open or short-circuited. The principal secondary terminals are then connected to the current coils of the meter, and the correctness of the connections checked by diagram and polarity marks, or any other suitable method, just as if the current transformers were of the ordinary type. This done, the voltage is removed from one element, and the direction and approximate speed of rotation of the disk are noted. The auxiliary secondary terminals of the current transformer which is driving the meter are then connected to the meter terminals, and as a check, the principal secondary circuit is opened. If the auxiliary coil has been properly connected, the meter disk will continue to rotate in the same direction and at practically the same speed as before. If the auxiliary coil was connected backwards, the disk will run about the same speed as before, but in the opposite direction.

The fact above cited simply means that the auxiliary winding is a corrective device capable of functioning not merely over a limited range of error in the principal secondary current, but even in the extreme case of the absolute failure of the principal secondary current the meter will be kept running at nearly the correct speed.

It is obvious that other means may be used for facilitating correct connections, such as a cable of secondary wires of different colors, with corresponding markings on the meter terminals. In any case, the method of checking just outlined is simple and easily applied.

Answering Mr. Borden's question about the elimination of the extra winding in the meter, we would say that a considerable amount of work was spent on this point. By proper precautions, very accurate results may be obtained, but it is necessary for the best results to use a rather large burden in the principal (non-precision) secondary circuit, and furthermore, to have means for checking the accuracy. With the use of duplicate windings on the meter, low burdens may be used in the principal secondary circuit if desired, and if the transformer has been properly made and checked at the factory, no means of checking the accuracy are required, save only to see that the connections are properly made as above outlined.

DISCUSSION ON "TRANSMISSION LINE RELAY PROTECTION*—II" (Hester, Conwell, Traver, Crichton.)

Niagara Falls, Ontario, June 30, 1922

E. R. Stauffacher: The nomenclature and classification of various relays and the acceptance of this nomenclature by the Standards Committee of the A. I. E. E. is a distinct step forward. Relays are assuming more and more importance in their application to central station systems, not only where the load is largely concentrated, but where it is spread over a large territory covering, for example, one-half of a large state. In both cases it is quite necessary that the defective section of such a system be localized, even though in some cases it may take a couple of days for a patrolman to go over the line which is in trouble. The big job is to drop the defective section as soon as possible before it upsets the remainder of the system.

I have referred in a former discussion, to the difference in the Pacific Coast conditions as compared with the eastern conditions and I wish to mention now that the lines are quite long in some cases; 240 miles in our particular case being the longest line. We have only comparatively recently begun the application of modern relays to our system, and are just beginning to learn something of their fine points as well as their limitations.

We have a peculiar condition with our 150-kv. Big Creek line. Mysterious flashovers occur that are not associated with any particular kind of weather, any part of the day, nor any part of the night. It appears to be a hopeless task to find a reason for the flashovers and to eliminate them, so the next thing to do is to get rid of the defective section in our most important transmission line, even though we have to go counter to the opinion of some of the more conservative engineers. It has been decided, therefore, that when the line is changed to 220-kv. operation that the current balanced method will be used for eliminating defective sections. We are only planning to eliminate the first defective section. If the first section should go out on account of trouble and the second section should also get into trouble later, this second section will not be isolated by relays applied to the transmission line, but will be handled by means of a field-killing device on the generators at the power house. Current flowing to ground will operate certain contact-making ammeters which will cause a motor attached to an auxiliary "trouble" rheostat to cut resistance in the generator field as long as current is flowing to ground; and as soon as the ground current ceases to flow the contact-making ammeter will reverse its contacts and the motor will reverse, bringing the generators up to full voltage. Under present conditions, this operation is performed by hand and takes an average of approximately 15 seconds to handle a flashover. There it not much difficulty in handling a flashover manually when one or two power plants only, located two hundred-fifty miles away from the load are operating, but when we have three, four, and ultimately as many as eight power plants attached to one or two transmission lines, it will be necessary to have some automatic means of lowering the voltage in case the second transmission line gets in trouble.

Mr. Hester has emphasized the necessity of the manufacturers and the operating men getting closer together and has pointed out the fact that the operating men misapply a relay occasionally and I think that point is very well taken. We, in the west, located so far from the large manufacturing companies, find it particularly difficult to keep up with the latest applications, so I certainly would voice what Mr. Hester says—that a closer co-operation between the manufacturing company and the operating engineer would help a great deal in securing the best possible application of relay protection.

R. Bailey: I notice, in reading the paper, one thing which is emphasized throughout, and that is the tendency to do away to a great extent with time settings, working more with the balanced condition, where a defective line is removed from the system instantly. The elimination of the time delay has the disadvantage of causing the circuit breaker to open before the short-circuit current can decrease but it seems to me there is a good deal to be gained by removing the defective section so quickly that the synchronous equipment will not fall out of step. In many cases a cable failure may start as a breakdown to ground and the use of time delay relays may allow this fault to develop into a severe short circuit before the oil circuit breaker opens,

*A. I. E. E. Journal, 1922, Vol. XLI, November, p. 839.

thus increasing the duty required of the breaker and leading possibly to a system disturbance.

Most of the schemes presented, I believe, are open to the objection that they do not protect against the failure of a station bus, but it looks to me as if this is not a serious objection, as there have not been many cases of bus failure, due no doubt to the precautions taken to obtain liberal design and sturdy construction of busses.

Most of the differential or current balance schemes are applicable where three or four lines are operated in parallel, but where it is a case of operating just two lines in this manner, the schemes do not work out very well. This is a real objection because on a number of systems it is the practise to operate just two lines on the same bus section rather than three or four in order to limit short-circuit currents. While it is true you can get better continuity of service with three or four lines in parallel, the magnitude of short-circuit currents may prohibit this practise. Then, again, the differential scheme usually involves interconnection of transformer secondary leads, which is not in accordance with the idea of completely sectionalizing equipment to prevent the communication of trouble from one line to another.

Most substations are provided with double busses, which further complicates the application of differential relay protective systems, and in some instances make it inadvisable to use a scheme of this sort.

In one place in the paper a scheme is suggested which involves grounding one phase of the system at the time of a ground on another phase of the same line in order to cause the excess current relays to operate. While this will no doubt separate the line from the system it may cause a serious disturbance and it would therefore appear to be advisable to provide other means for isolating such a line.

In closing I wish to emphasize the need for simplicity of all relay protective systems. A number of them which will theoretically, do the work intended are rather complicated and therefore difficult to keep in condition, resulting possibly in failure to function. It is rather unfortunate that in some cases such systems are not given more care in the design and installation, and in their maintenance afterwards. This condition seems to be due to the fact it is not realized that the relay protective systems are far more important than the investment involved would indicate.

Paul Ackerman: Relay protection is a wholly defensive measure and does not appear to produce any revenue. As a result it is usually very difficult to requisition the necessary money for such expenditures. Yet there is nothing more important than an effective relay protection to assure safety to a power system and to avoid expensive tie-ups to industries and disastrous destruction to power companies' properties.

Today, relay engineering is still about in the same stage as circuit breaker engineering was some ten years ago. In those days the size of a circuit breaker to be chosen and the money to be spent was determined by the importance or unimportance of the respective new feeder. Today, we fully realize that the oil switch to be chosen depends entirely on the main system to which the respective feeder will be connected.

Relay protection is mostly handled in a fashion similar to that in which circuit breakers were chosen some years back, the feeder to be protected only being considered. Yet an effective relay protection is possible only if in each case the main system as well as the respective feeder are given careful consideration.

Regarding the differential current schemes described in the paper, I am gratified to see that this principle has received general consideration within the last few years.

It was as far back as 1912 when I conceived of the scheme illustrated in Fig. 4, and ever since I have been working along similar lines despite great opposition.

The objections then raised were the same as those mentioned in the paper, that is, complication of wiring and interconnection of current transformer secondaries of different lines. The best proof that these objections are not very serious lies in the fact that those who raised the greatest objections originally are today the most ardent supporters of these protective schemes.

There is no doubt that all differential current schemes are complicated in wiring, but it must be remembered that wiring connections are made once only and if properly made are permanent and safe so that no trouble should be experienced from this cause. The relays themselves on the other hand, can be made of such elementary construction that they are usually much safer than the more complicated time-limit over-current or directional relays.

The checking of phase relations is usually much simpler and more definite on differential current schemes than on directional relays.

The paper mentions also as one objection of the differential current scheme the fact that they require several relay contacts in series. In this respect, it may be pointed out that no fear from this cause need be entertained as long as the relays are of simple structure. The best proof of this is to be found in the fact that of the several hundred relay actions of the different schemes illustrated in Figs. 4 to 7, there is not a single failure which could be attributed to this cause.

From my experience, it is usually safer to adopt a scheme with simple relays and several contacts in series rather than reduce the number of contacts at the expense of a more complicated relay. Such complication in the relay structure is invariably required if a similar effect is to be obtained. A comparison of Fig. 1 and 7B is an example of this kind. The two schemes are fundamentally the same except that Fig. 7 attains the results by two relays with the contacts in series to each other whereas in Fig. 1 a relay has been developed which requires only one contact, combining the two functions cleverly in one relay, thus, however complicating the relay structure.

The paper mentions another drawback of differential current schemes being the fact that they are unable to take care of bus bar short circuits and that for this purpose additional overload protection is required. In this respect I might say that the power companies will have to realize that they will never be able to obtain a relay which can perform all the required functions and accordingly they will have to accustom themselves that several different type relays will have to be installed on the same switches in order to cover all possible conditions. I might mention as an example that I have come across cases where I considered it essential to install as many as 5 or 6 different types of relays on the same line.

With respect to the various differential current schemes, illustrated in Figs. 1, 3 and 7 used for double line protection, it will be noticed that they are based on the same fundamental facts but that the means employed are different.

Schemes shown in Figs. 3 and 7 report provision of blocking of the protection of the remaining line after one line has opened. The description for Fig. 1 leaves the impression that no such blocking is provided. If such is the case, I would point out that under certain conditions where the current setting of the relays must be made very low, this omission may lead to trouble.

It must also be clearly understood that the various differential current schemes have certain limitations which have to be kept well in mind.

Open-circuited phases for instance, have the tendency of tripping the wrong line unless the relays are set higher than the total load fed over the two lines.

There are also conditions arising where an arc sometimes clears after one line end has been opened. Under such condition, the danger exists again that the other end of the other line may open wrongly and thus cause a total interruption. This danger exists wherever the recovery current may be heavy and where the relays have comparatively low current setting.

These limitations are of little consequence on underground systems where open circuits and self extinction of arcs are very

rare. Also on copper lines where cable breaks are rare or on short overhead lines of pin type construction where arc extinction is less to be feared, little trouble should be experienced with differential current protection.

The conditions are somewhat different on long overhead lines, particularly with aluminum cables where breaks are more likely to happen, and where arc extinction is more pronounced.

The above is clearly indicated by the fact that the protective scheme as per Fig. 7 has given practically 100 per cent effectiveness on single line shorts on a 90,000-volt pin type copper line whereas the effectiveness seems only to be about 80 per cent on some other lines of aluminum and suspension construction.

Regarding the differential current protection for 3 and more lines as illustrated in Figs. 4, 5 and 6, I would like to point out the effectiveness and simplicity of this scheme. The simplicity lies chiefly in the fact that relays of the simplest type can be used and that no blocking relays are required. The wiring, though somewhat complicated, can be made fairly simple, particularly on 3-feeder protection, especially if scheme 6c is used. The scheme adapts itself particularly to underground distribution where substations are very often fed over three or more cables. In such cases, it is usually very rare that operation is maintained with only two, or one feeder, or under any such condition one is usually satisfied to have a protection on two feeders which at least does not operate wrongly on through short circuit, while mostly it may be acceptable to cause an interruption under such operating conditions in case of trouble in one of the two cables.

For any such case, this scheme is splendidly adapted and decidedly advantageous compared with scheme, Fig. 2, as to cost as well as simplicity of relay equipment.

Regarding the merits of directional relays combined with overcurrent relays, it is quite evident that considerable improvements have been made on the directional relays, making them operative down to very low voltage. Modern connections also leave the directional relay effective on single-phase shorts. Still the facts remain that the arrangement should be used cautiously and reluctantly on higher voltage systems, and particularly overhead lines since under such conditions single-phase short circuits often develop rapidly into three-phase short circuits, thus making the action of the directional relay doubtful unless the arrangement is such that sufficient voltage is left on the relays to operate effectively.

No doubt for certain conditions there are no other means available at the present time. The best proof of the limitation of this principle, however, can be seen in the fact that the differential current schemes have been able to make such rapid headway within the past few years.

Regarding the split-conductor principle and the pilot wire principle, I must confess that I have no sympathy with these principles as far as their application for transmission and distribution lines are concerned, except possibly for very short runs.

Both principles in themselves are ideal in view of the fact of clearing both ends of the faulty apparatus simultaneously. For generator and transformer protection they are ideal and deserve more general use.

For line protection, however, the complication, the hazard and the cost are becoming excessive as soon as the lines or cables exceed one mile in length and it is my firm belief that under such conditions they are not able to compete with the differential current schemes, with the exception of very special cases.

The advantage claimed for the split-conductor and pilot wire scheme of having no interconnection between adjacent lines is in my opinion far more than counteracted by the complication and hazard introduced in the split-conductor cable and in the pilot wires respectively.

It is also claimed that the split-conductor or pilot wire schemes are able to limit the damage on cables and the effect of the disturbance on the system because they are supposed to clear the fault before a complete breakdown has occurred. I believe that this view is erroneous. I cannot conceive of any fault, after having developed sufficient current to operate even the most sensitive relay to take longer than 0.3 sec., which is the rupture time of the oil switch, until it has completely broken down. In my opinion, a dead short circuit is developed within a small fraction of a second after any appreciable current has started to flow through the fault, so that the short in practically any case should be completely developed before the oil switch had a chance to open, even if tripped by the most sensitive relay. The limited damage, therefore, in my opinion is caused by the rapid clearance of the short by the quick acting breaker but not by clearing the short premature to the complete breakdown.

Very similar results are observed from the action of differential current protection; flash-overs on overhead lines, cleared by the differential current protection, never damage the insulator sufficiently to disable the line permanently unless the insulator punctures. Cable faults are cleared without undue damage but just sufficient to permit detection.

Split-conductor and pilot wire schemes, therefore, are in no way superior to differential current schemes in that respect.

With respect to the ground selector, I would like to comment on one statement of the report. The paper mentions that the chief disadvantage of the ground selector would appear to be the loss of the advantage of the permanently grounded system. In my opinion, the reverse of this statement is rather correct.

Ungrounded neutral has always been found preferable in many respects, chiefly in regard to transformer connection and the total number of interruptions. The chief drawback was the difficulty of locating grounded feeders and the damaging effect caused by lasting grounds.

The preference given to grounded neutrals is entirely due to a desire to overcome the above serious trouble. This is true at least for voltages up to 60,000 volts.

The ground selector performs on the ungrounded system the same duty for which the grounded neutral has been introduced but with the benefit of being able to retain the advantages obtained from an ungrounded system.

The ungrounded system, therefore, equipped with a ground selector, combines in my opinion the advantages of the ungrounded and grounded system without, however, having any of the disadvantages of either system. The results on the 12,000-volt Toronto distribution show particularly how great a number of self-clearing grounds are given a chance to clear without any disturbance whatever, whereas with a grounded neutral each one of the self clearing grounds would have meant a voltage disturbance and a partial interruption.

Regarding the keeping of records on the functioning of relays, it cannot sufficiently be emphasized that it is very essential to collect as exhaustive information as possible. It is very important, however, to try to obtain the correct information.

For instance, a total interruption on a double line system protected by a double line protection can be caused either by a double line short circuit or by wrong relay action.

Past experience has made the operating man so suspicious of wrong relay actions that he is inclined to dismiss any such case without further investigation by considering it simply a wrong relay action, whereas possibly the relays were acting to the best of their ability.

Short circuits across two lines built on the same tower line or in close vicinity on the same right-of-way are not as unusual as thought. Such possibilities must be given careful consideration before blaming the relays.

On the other hand, each case of wrong relay action must be carefully studied to find the reason for such behavior. Only thus will it be possible to gradually develop the necessary improvements.

In closing, I wish to emphasize that we must not be lured into the belief that we are about to enter the stage where protective schemes are available to cover all the various conditions. On the contrary, we have only just started to realize that our old pro-

tective schemes are obsolete. Much hard work will still have to be done to develop the standard of perfection which will be required on systems such as the super-power scheme.

It must also be remembered that the various protective relays of a system have to be properly coordinated and that this can only be done by having this matter centralized in the hands of one man who will be able to concentrate his whole thought on this one problem.

It is also essential that each system be studied on its own merits, also each individual problem. To copy other companies' practise, without careful analysis of the fitness to the conditions under consideration, may lead to very disastrous results since a scheme may be fully effective in one system and a failure in another one. The work of the Relay Committee acquainting us with different schemes must be accepted with that fact in view as otherwise the Committee reports may become misleading.

E. M. Wood: Possibly you may be interested in a description of some rather unique features of relay protection we have in the Queenston power house. You will notice from Mr. Gaby's paper that we have used the current differential relay system to a large extent to protect the busses and other equipment in the station. We have found in some other power houses that we have trouble quite frequently on the busses and it was considered necessary to protect them.

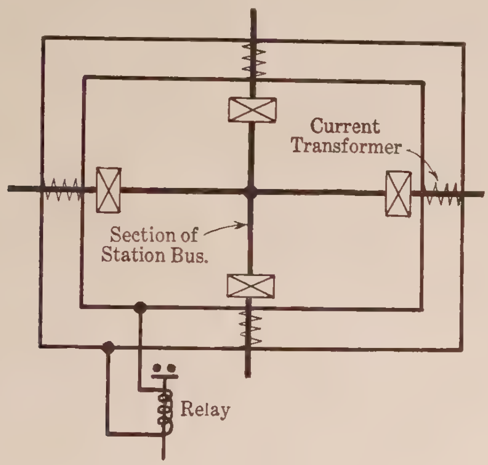

Fig. 1

The scheme which is used can be shown in diagram (See Fig. 1). We have this on the generator, on the 12-kv. bus, and high-tension bus, and on the transformer bank. The relays used are plunger type and give quick operation in order to cut out defective equipment as quickly as possible, and if possible leave the rest in. On the outgoing lines, we have the inverse-time overload induction type of relay. It is our intention to use current differential protection on parallel outgoing lines to the same substation.

A study of the plant characteristics seemed to indicate that there would be a danger, under certain conditions of partial rejection of load, that the machines would drift apart. We have therefore used inverse-time overload relays between bus sections.

In the case of the current differential relay there is always a certain suspicion that possibly it will operate when it should not. In order to overcome that, we have taken considerable pains to get current transformers that maintain their ratio. Secondary connections between current transformers are kept short and the long runs to the control arm carry only the residual current.

There is also installed a reverse-current relay of the spring restrained instantaneous three-element induction type on each generator intended to trip out in case of careless synchronizing. As our differential groups of current transformers do not include the delta bus and low-tension terminals on the transformers we have installed a ground relay to trip in case of ground on that section of the wiring. To date the relays today have operated as they were intended to operate, and have not operated when they were not intended to do so.

R. N. Conwell: In the announcement of this paper the statement was made that "relays do not constitute a profitable business." Undoubtedly, the writer of that phase had in mind development and manufacture of relays. The question, "Do relays constitute a profitable business for power companies?" may be answered just as definitely if accurate interruption and relay operation records are kept.

The question has been answered by one operating company and it is hoped that the presentation of the results of the analysis by which the answer was obtained, will lead other companies to make similar analysis.

The interruption and relay operation records for a five-year period on thirteen typical substations or about 15 per cent of the total number of substations in the system were examined and all interruptions which were unavoidable or not chargeable to relay protection eliminated. These interruptions included those due to operating mistakes, failure of oil circuit breakers, bus short circuits, failure of control or excitation sources and similar causes.

The relay protection in 1917 was no better nor worse than that to be found on many systems today. Intensive relay work in the field was started in the spring of 1918. The table shows the results of this work.

NUMBER OF AVOIDABLE INTERRUPTIONS

Substation	1917	1918	1919	1920	1921
A	26	7	9	4	0
B	15	6	4	1	0
C	8	4	3	3	0
D	7	3	1	0	0
E	17	12	3	1	1
F	35	37	9	12*	6
G	26	7	8	2	0
H	22	21	7	10*	2
I	18	41	9	16*	3
J	23	8	8	6	0
K	11	0	2	0	0
L	48	22	5	12*	9
M	15	3	5	3	0
Total interruptions......	270	171	73	70	21
Total cases of trouble....	288	302	185	212	130
Interruptions per case of trouble...............	.94	.57	.39	.33	.16
Lost revenue............	$8500	..	..	..	$150

*Increase due to the most severe lightning season in the history of the company.

Capital Expenditure for Improved protection.......	$25,000.00	
Fixed charges at 15%.......................	3,750.00	
Engineering, maintenance and testing.........	4,300.00	
Annual charge (13 substations)...........	$8,050.00	
Recovered Revenue basis for 1917-1921 figures.................		$8350.00
Annual profit................................		$300.00

On the basis of these figures, relay installations in this company "do constitute a profitable business" for in addition to a small cash dividend, they pay a much larger additional dividend in the reduction of damage to apparatus and equipment, and the increase in the good will of actual and prospective customers, by insuring continuity of service.

There is an interesting point in connection with Mr. Ackerman's discussion on the question of the grounded neutral. On this particular system, which consists of 13,000 and 26,000-volt lines, covering quite a considerable territory, the neutral was grounded in November 1918, and you will note the decrease of the cases with trouble after the grounding of the neutral, I think that this decrease is strictly chargeable to the grounding of the neutral.

A. H. Sweetnam: One of the larger central station companies has made during the past year rather extensive application

of power unidirectional relays. The system so protected consists largely of multiple lines, supplying a number of substations in series.

There have been two cases of incorrect operation—that is, the unidirectional relays in one station have operated when the fault (a cable failure) was found beyond the station in which the relay operation occurred. In each case it was later found that one potential transformer fuse was blown resulting in changed relation between current and potential in the individual relays.

To avoid the probability of a repetition of such incorrect performance it was suggested to the manufacturer that three potential transformers be operated in closed delta with six primary fuses. The reply advised that this plan would be entirely feasible but that no difficulty would be experienced if a change were made to the fuse supplied by this particular manufacturer.

Notwithstanding this recommendation, the practise of this company now contemplates the use of three potential transformers and six primary fuses. It may be said that with six fuses the fatal day is only somewhat deferred, as with one fuse blown normal operation will be experienced until the second fuse fails. In this case, however, it is the practise to install a pilot lamp directly across the secondary of each potential transformer

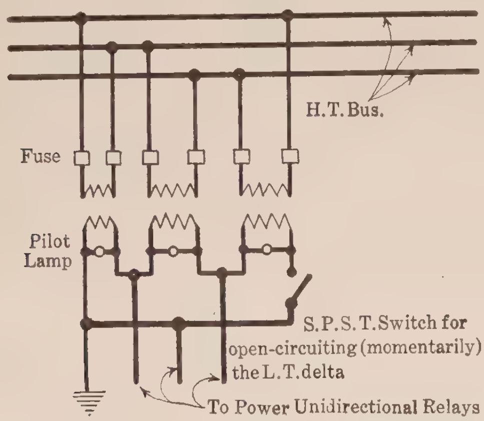

Fig. 2

and install a s. p. s. t. switch in the low-tension delta connection. In this way at intervals such as may be considered advisable the continuity of primary fuses may be checked. (See Fig. 2.)

E. P. Peck: One of the biggest sources of trouble or failures in the operation of relays that we have experienced was not due to the relays themselves but due to the changes in the number of generators at the station. In the season of the year when there are high water periods most of the load is carried on the water power plants, and in the season of low water periods, most of the load is carried on the steam plants,—a condition which makes it almost impossible to make the proper relay application. This month we may be operating through our low period of the day with five machines in service in the hydro plant. The relays at the station and on the line must be set so that if one line is out of service, the other line is perfectly suitable for carrying the load without danger of an interruption. Next month, when the effect of the extremely high water that some of us have had has passed over, we may be operating only one, or at most two, generators in the hydro plant with most of the load carried by the steam plant. We cannot go over the system and reset all of our relays, consequently during cases of trouble our relays may not function. We have not had any advice from the relay engineers as to what to do to take care of that trouble.

Quite a number of our relays were set in a waterproof case out of doors to save wiring, and on these we had some particularly serious cases of relay failure. We found there was a little corrosion at some critical point, which caused the relay to fail. As a result of one or two cases of that kind, we have inaugurated a system of testing all relays, wiring and circuit breakers on the system that can possibly be tested, every week. Starting at twelve o'clock midnight on Saturday we test every circuit breaker on the system that can be tripped, by closing the relay contacts. That practise has caught a large number of things that would have caused trouble.

Near the end of the paper (Dec. Journal), there is an interruption analysis sheet form given. I suggest that the name of the form be changed. A good many of us are keeping interruption analysis records now, and the interruption analysis records are very different from relay operation records. I think the better heading for that sheet would be "relay operating records" so that the stenographers will not always be pulling out the wrong report when you want the relay operating record.

W. H. Cole: Some four years ago I presented a paper at a meeting of the Institute on "The Experience of the Boston Edison Company with Balance Protection," including our experience since 1913 with split-conductor cables. At that time the operating experience was rather limited, but at the present day we can say we have had an operating experience with six-conductor cables amounting to 600 mile-years. In other words, 600 miles of cable for one year.

Everything brought out in the original paper regarding the advantages and troubles incident to the use of these cables has been confirmed by more extensive experience in the last four years, and all of the good points mentioned previously have been continued, and a great many of the doubtful points have been cleared up, so that they are now favorable.

As we analyze the situation the principal objection against split-conductor cables or pilots wire protection of any kind is the extra cost. It is admittedly high and it is admittedly worth while, but money talks and other schemes are being applied utilizing standard lines to almost the same advantage as we get with split-conductor cables or other pilot wires.

Another objection to the use of special cables is the fact that they require more duct space, and it is a vital objection, because we may be able to install 250,000 cir. mil of one type of cable in a given duct, and with the regular cable we might be able to install 350,000 cir. mil and it is a large item, but, on the other hand, the protective scheme is undoubtedly ideal. The only question is—What is it actually worth? That applies equally to the pilot wire scheme which has been perfected to a greater extent than formerly, and some of the original objections eliminated, so it has come back, especially where another duct space is required, and the pilot wire is laid in the open ground as it does not need a duct.

One of the objections to the split-conductor cable raised abroad is that by a large undertaking over there, regarding the telephone system. Usually they lay the common telephone cable, and in laying this they find it quite inexpensive to employ three pilot conductors. With the Merz-Price-Beard system, as improved by Burd and Hunter, the application of pilot wire protection in the telephone service, has brought the cost down so that it is lower than split-conductor construction. That is merely a question of economics, but everybody who has had any large experience with split-conductor cables and pilot wire control are willing to say it is ideal, and that the problem is more a question—Can we afford to pay the price?

O. C. Traver: Mr. Ackerman remarked in connection with the balanced schemes described for the protection of two parallel lines that if one of them should become accidentally open-circuited, it would have a tendency to open the other good line. While this is true there does not seem to be any material hardship resulting in practise. Furthermore, I believe the difficulty equally true of the other schemes mentioned by Mr. Ackerman as well as any balancing scheme when two lines are involved. In the same way when three lines are balanced practically any of the schemes described in the paper will properly take care of the matter in substantially the same manner as the one referred to by Mr. Ackerman.

I would like to add a word of caution in regard to the adjust-

ment of relays used in the protection of systems with comparatively high resistance from neutral to ground. This warning is not intended in any way as an alarm, because in many cases the system has excellent possibilities. I know, however, that in a number of instances where ground current has been limited by resistance some of the resulting effects have been overlooked. Particularly in those cases where grounding transformers are located at some place other than the generating source, the intensities of the currents and the directions of power in case of grounds are entirely different from those resulting from phase to phase shorts. It, therefore, requires in most cases a complete separate analysis of the proper current and time settings and a very careful check on the question of directional relays.

H. T. Plumb: We will cite an instance where relays worked successfully. Five years ago relays were applied to the principal three-phase transmission line in Utah, operating at 130,000 volts and transmitting power from the plants in Idaho to Salt Lake City, 135 miles. Settings for the relays were worked out on a calculating table. These settings have not been changed in five years and the relays have given practically 100 per cent performance. There has been only one failure which is possibly chargeable to the relay. This is conclusive proof that these relays work.

With regard to the remarks of Mr. Stauffacher and his difficulty with curious short circuits this transmission line of which I speak was subject to very peculiar and many short circuits or flashovers between conductors. There were various theories for these failures. Some thought it might be due to the numerous swarms of small flies out of a nearby swamp. Others imagined many curious things were the cause of the trouble, but they never were sure of the cause. That was nine years ago and the trouble has not recurred. The most generally accepted theory is that the short circuits were caused by large birds, and that these birds did not leave evidence as to what had actually happened. It hardly seems possible that birds could receive the full line pressure, 130,000 volts, get away with a few burned feathers, and never leave anything else behind. In any event it seems that experience with the live wires taught these big birds how to alight on the towers, and to fold their wings so that they will not make a short circuit. Young birds might start the trouble again until they learn to be cautious.

L. N. Crichton: I would like to emphasize the question of simplicity in relay installations. It is easy if you work long enough and painstakingly enough to devise a scheme which will fit every requirement of a complicated system. But sometimes you find you have overlooked something, and other times you find that the scheme is so complicated that the men who operate it do not maintain it properly. In reading this report, it is important to remember that many operating companies have gotten over the trial period, and they no longer have any *trial* relays. One of the largest operating companies has 342 sections of lines protected by carefully designed relay schemes. This requires 1845 relays and 644 automatic circuit breakers. Bear in mind that this refers only to the devices for automatically sectionalizing the network and that these figures do not include the devices for protecting apparatus. This extensive relay system is justified not only by the improved service rendered, but also by the saving in copper which results from the close interconnection of feeders. Incidently, this system uses only the simplest schemes of relay connections. Now, by way of prophecy, the calculating table will become of less importance and the more or less laborious calculations now necessary to determine the proper relay settings will decrease as the relay art advances. Relays are being developed which will determine the location of short circuits and will operate only when the trouble is close to them. Elaborate calculations will not be necessary since each relay will make its own calculations when the trouble occurs.

It is possible that a description of such a relay will shortly be presented under the auspices of the Relay Sub-Committee.

W. R. Bullard: The description of the ground selector relay scheme of which Fig. 18 is a wiring diagram is particularly interesting because of its similarity to the operation of the so-called "arcing ground suppressor." However, the results accomplished by the latter are just the reverse of those described in this paper in that the arcing ground suppressor is used to ground the leg on which the fault occurs (instead of an opposite leg.) It therefore suppresses the arc and prevents it from producing a short circuit. Up to the present time the chief application of this type of apparatus has been in connection with distribution systems. A number of these suppressors are in actual use on such systems and have apparently been giving remarkably good service for several years. Their main advantage lies in their ability to eliminate the occurrence of a large number of short circuits and thereby reduce the number of outages. However, there is no apparent reason why the same scheme could not be applied to transmission. Such application would seem to be a more logical one than that of the scheme mentioned in this paper, since the effect would be to minimize the disturbances on the transmission system instead of deliberately creating them.

The authors lay particular stress upon the development of balanced protection for parallel lines. These schemes have a considerable number of advantages, the chief one being that of minimizing the necessity for a large number of selective time settings. However, one great disadvantage of some of these schemes lies in the necessity of keeping all the feeders of a group in service to secure the proper operation of the system. I am sorry that more space has not been given in this paper to detailed description of operating conditions under which these schemes have been used, and specific methods of over coming this difficulty.

Referring to the various schemes which have been developed for ground protection, the chief advantage of this form of protection lies in the ability in some cases to use extremely low time settings thereby disconnecting the faulty unit before a phase to phase short circuit has had time to develop. It is stated in the review preceding the paper that the application of these relays with regard to current and time settings is based on the same principles that apply to relays used for short-circuit protection. However, it should be noted that where two or more selective time settings are used, the purpose of the special protection is in danger of being defeated by the greater time taken to clear the fault. It would therefore appear that the only real solution to the problem in this case would be the combination of ground relays with other more expensive schemes, such as pilot wire and other such systems.

S. W. Mauger: Too little attention was formerly paid to the subject of protection of lines both by designers and operators, the former not being able to appreciate the requirements, until the operators awoke to the necessity of further study and placed the condition more clearly before the designers.

In many cases, relays were simply considered as auxiliary devices to cause circuit breakers to open in case of trouble. The broad subject of continuity of service was not thought of in connection with relays which indeed were thought of only as *interrupting* continuity.

Modern relays, although comparatively insignificant in themselves, when properly applied, make it possible to maintain continuity of service with stations interconnected to give maximum efficiency of conductors. This may result in some cases in the saving of thousands of dollars in investment, as the multiplying of circuits and the isolating of stations to avoid general shut downs is obviated.

As a result of the awakening to the real needs which were becoming more and more serious due to expanding systems, the manufacturers in cooperation with the operators went into the subject intensively and at considerable expense and they are now able to furnish relays to meet practically all conditions. There is still much work to do on the part of the manufacturers but they are alive to this fact.

Many operating companies are giving the matter serious attention, but it is feared that there are many more who are not and it is hoped that the relay paper under discussion will be earnestly studied by all operating companies. I would particularly stress the matter under the headings of "The Calculation of Short-Circuit Currents," "Relay Application," "General Practise in Relay Settings and Tests" and "Operating Records."

DISCUSSION ON BALTIMORE OIL CIRCUIT BREAKER TESTS* (Louis and Bang), TESTS ON GENERAL ELECTRIC OIL CIRCUIT BREAKERS AT BALTIMORE† (Hilliard), TESTS ON WESTINGHOUSE OIL CIRCUIT BREAKERS AT BALTIMORE‡ (MacNeill),

Niagara Falls, Ontario, June 30, 1922

B. G. Jamieson: I would like to make an announcement which I was commissioned to make by the Subcommittee of the A. I. E. E. on oil circuit breakers. We have as a heritage a definition of duty cycle, which is fundamental in determining the rating of oil circuit breakers. That duty cycle, as defined by Hewlett, Burnham, Mahoney in a paper written about four years ago, represents the sumtotal of available literature on the subject. The adoption by the American Institute of Electrical Engineers of a standard definition is based on that paper.

Unless we know what the duty cycle is, we do not know much about what the breaker will do, because we cannot purchase and install breakers on an equitable basis.

One of the authors who presented a paper has emphasized the point that as the result of the Baltimore test it is a fair assumption that the closing of the breaker on the short circuit is something of rather slight importance. A representative of another company, equally interested, has stated that it is a matter of paramount importance. Whatever the facts may be, you will notice that in all circuit breaker tests conducted in this country, at least, the manufacturers have always been very careful to close in the "first" and use the second breaker.

I think we ought to know the facts on that point, and that brings me to a point I want to refer to specifically in connection with the announcement just made. The A. I. E. E. subcommittee on oil breakers has had a great deal of difficulty in defining specifically where the duty cycle should begin, and where it should end. It had some difficulty in putting into words in which there was no ambiguity, just what the condition of the breaker should be at the end of the test. That matter has been disposed of. It has also been agreed that the breaker duty cycle should terminate with the switch in open position.

About the beginning of the duty cycle the old ratings are said to have had for their intent the assumption that the duty cycle should begin with the breaker in the closed position, and that the standard rating of breakers is what is known popularly as two "shots." We are to understand that the breaker is supposed to be on the bus, and if opened once, it may be reclosed on the short, and open once more and then we are done, but we must know that the breaker is capable of being closed in on the short in the beginning. Some men have gone so far as to say that it does not occur, and others say it does not occur often.

There is another position which can be taken, namely, a breaker in a power station, 200,000 kilowatts, closed in on short circuits—and I can testify it does occur at times,—it seems almost preposterous to say that we should withdraw from the specification, that the breaker must be capable of being pulled on, on a short, and opening it, it must be assumed that the breaker was first on the bus.

Recently I sent out a questionnaire on this point and got some replies. Unfortunately, the opinions were about evenly balanced. The Committee instructed me to send out another questionnaire, with the purpose of getting an opinion from every operating man as to whether or not it would be better for the definition, at least the definition given in the American Institute rules, to specify or not specify the breaker as capable of being closed in, on the short. I will draw your attention to the specifications for the 3-shot and 4-shot breakers. In the case of the 3-shot breakers, at the 299th shot, the breaker must be closed in on the short, and the operator is supposed to close them on the first shot on the lower ranges.

We still have the option of operating breakers with the same degree of practical safety we have always had; it is simply putting the definition in the logical form, which will not require justification in the industry, either nationally or internationally.

I want to say that questionnaires will be framed by representatives of the A. I. E. E., the N. E. L. A. and the Power Club, so that there will be no doubt about the way in which this question is presented.

Referring now to these three papers, central station systems now require transmission system equipment of a few years ago for distribution, purposes. Immediate prospects of super-power systems behind this equipment and further electrification of industrial and railway systems beyond, focus our attention on those devices upon which the safety and thereby the practicability of this enormous energy combination depends. This makes particularly conspicuous the oil breaker, the most important of all protective devices.

The knowledge that these tests were being conducted during the past year or two and the realization of their importance has kept us in an anticipatory state of mind, and it is, indeed, gratifying to learn that in the opinion of those most concerned the result of these tests point to successful achievement in breaker design.

I would like to qualify that statement a little bit saying that whereas that may be a bare statement, but regarding the results of these tests, the question is still before us as to what shall we do with the vast number of breakers that we have on our systems, which are, at least, open to suspicion as to their interrupting ability. The various expedients that are being adopted, such as the installation of reactors and sectionalizing of systems are all practical enough, and very expensive, but it seems to me that what we are most interested in is not whether a breaker can be designed to interrupt a small amount of energy, but the question is—Can we afford to depend upon breakers for the isolation of defective portions of our system, or is the result going to be the development of a breaker we can afford to use? Perhaps that is not an Institute matter, but I feel it is at the bottom of a great deal of the trouble which we are now having.

When we reflect that inadequate breakers may transfer system trouble from a remote point into the generating station and possibly on the bus at that point, interrupting service, damaging property and endangering life, it is clear that everything should be done to establish fully the efficacy of oil breakers as a type, otherwise our protective engineering is but a grim travesty. At this point I would like to explain that the word "inadequate" does not mean defective; it means insufficient, which is often as chargeable to the operator as to the manufacturer, perhaps properly more often.

It is essential also to determine the functional capacity of oil breakers as energy interrupting devices in order that other elements of the system or new devices may be made available to compensate or substitute for the conventional types of breakers beyond their established limitations. By that I mean that when some little device which may now be in the minds of research men, makes its appearance and makes big circuit breakers look like a joke, the sooner we know about that the better.

Referring more specifically to the data as published in these papers, several important factors stand out. First, all short circuits were made beyond the closed test breakers. This method of test seems to some of us illogical, particularly so in consideration of the duty characteristics of reclosing breakers

*A. I. E. E. Journal, 1922, Vol. XLI, June, p. 399.
†A. I. E. E. Journal, 1922, Vol. XLI, July, p. 530.
‡A. I. E. E. Journal, 1922, Vol. XLI, July, p. 537.

which are required to close in on a short as well as to interrupt the short circuit.

I am not advocating the repeated closing of heavy duty breakers. I agree with Mr. MacNeill that it is unimportant, relatively, to the operator, to know what a breaker will do five or ten times. It does not matter whether the breaker stands up or not, but such service as that in a commercial system is beyond the requirements. The effect on the system, drop in voltage, and loss of synchronism, produces a mechanical stress, and weak points which no one suspected, may be developed. I desire to repeat the statement, that is, what we should know is what a breaker will do once. I do not say that we should buy a breaker on that basis, but we should know if breakers, for which we pay thousands of dollars, will do the things they are designed to do in an emergency which occurs seldom.

There should be no uncertainty as to how a breaker in a switch center of a large system will perform if it be closed in on a short circuit; the fact that such an event seldom occurs, notwithstanding. The importance of the successful performance of the breaker under such conditions is of such an order that there should be no question about its functioning. On the other hand, all tests were made with dead metallic shorts. This is an extreme condition which is seldom met with except when the breaker is closed in on a short by reason of some wrong connections. It is difficult to conceive of a dead metallic short (other than grounding devices) simultaneously established on three phases in a modern power house. Cable dielectric faults perhaps come closest to such a condition, but the average cable fault is usually at some distance from the power house. At this point I would like to call the attention of operating men to the great hazard of grounding generating station buses, more particularly the practise of simultaneous three-phase grounding which underlies modern methods.

In the Louis and Bang paper the fact was brought out that 77 per cent of normal voltage was re-established immediately after the arc. That is interesting and together with the statement that the larger percentage of short circuits seemed to break at the zero point corresponding to the time at which the stored energy is a minimum, are very significant, and would undoubtedly be the subject of a very profitable discussion, particularly for those who have in mind future tests on the same general order. If it is a fact having general application that tests may be more properly conducted at a point remote from the generating center, then tests of this sort may be combined with tests on relays, reactors and other protective devices functioning with the breaker. Also, reference to the effect that single and two-phase shorts caused severe vibration of generators, and to the effect that in no case did the generators fall out of step, are in my opinion noteworthy facts having a fundamental bearing on the results recorded in this series of tests.

Please consider these two facts together with the previously stated fact, that the tests were made by means of dead metallic shorts on a system having a solidly grounded neutral.

Now what I desire to bring out is that while we have obtained performance data of great value, in connection with certain types of breakers functioning under effects of short circuits, systematically applied, and obeying very closely their natural decrement laws, with generators supplying the energy in rythmic harmony, and with voltage transients apparently suppressed, that unless more definiteness is given to the effects of short circuits originating as single-phase faults and undergoing cycles of reestablishment, of generators out of phase with one another, as a result of the short and with voltage transients present, we may have our oil breaker rating based on "average" arc amperes at normal voltage brought into question.

In the paper by Mr. Hilliard an italicized statement on the first page seems at first reading to rather tend towards a discounting of the value of these tests by its restricted wording. Most engineers will understand what was intended by this statement, but it will be unfortunate for the art if an interpretation to the effect that these tests were special gains currency, thereby minimizing their value for deductions of a general nature. It is noteworthy that the duty cycle on the breakers included five successive interruptions at two minute intervals instead of the conventional number of two.

Statements that oil deterioration is not the factor which will determine the number of interruptions that can be made is comforting to know, if it is a fact that has general application. Combining this statement with the expressed assurances of the manufacturers that they are able to prevent the throwing of oil, and with the statements made elsewhere that tanks can be built so there is no danger of bursting, we find that the problem of successful breaker operation is reduced to the maintenance of arcing contacts, which the manufacturer unreservedly applies to oil circuit breakers of any type; this, then, becomes the crux of the whole matter, particularly where the duty cycle of the breaker requires repeated operation.

The paper by Mr. MacNeill imposes less restrictions than the paper by Mr. Hilliard insofar as the making of deductions from the results of these tests is concerned. The switches tested were of the general form of oil breaker built by the Westinghouse Company for many years, the improvement being largely in methods utilized to prevent throwing of oil and the relief of pressure caused by the arc gases. It is of interest to note that the author is able to point out definitely that throughout the test the arc was always ruptured at the zero point of the current wave. This assumption has been questioned at times in the past.

The suggestion of a differential rating for switches on 25 and 60-cycle service is another point which it seems to me to be worth considering in the determination of switch duties.

Attention of committee members is also directed to the statement of the author in the closing section of his paper regarding the effect of sustained voltage in imposing the maximum duty. As is stated, very misleading results are likely to be obtained in calculations of circuit breaker duty or performance where sustained or re-established voltage values are not given proper weight. This point appeals to me particularly in connection with private and committee work where failures of breakers have been reported. I think it is safe to say in general operating systems are woefully short of the proper registering devices to enable definite statements to be made regarding the successful or unsuccessful operation of breakers on system disturbances.

In closing, following a thought suggested by the specification appearing on the first page of this paper, which reads "all tank structures and mechanism parts are dead and can be solidly grounded," in consideration of recent experiences and previous convictions of the operating personnel of our own company and with due regard to the development of iron clad central station switch gear, I believe that the art of developing safe oil breakers on systems backed up by heavy power will be a problem of considerably less magnitude accordingly as we remove solid grounds from proximity to the arc rupturing elements of the present conventional type.

A. A. Meyer: Regarding the risks the central station companies should assume for conducting oil circuit breaker tests, I might call attention to the tests which were made by the Detroit Edison Company about five years ago. These were similar in many repsects to the Baltimore tests, and while they were not so numerous, they were of about the same magnitude.

One feature I think should be pointed out here, viz., that the large connected kv-a. capacity which was mentioned in connection with the Baltimore tests, was not all concentrated right at the point of the short circuit. In addition to the limited generator capacity at the short, there were several inter-connected feeders several miles in length and having an appreciable impedance.

Another item worthy of notice, is the fact that these tests were conducted usually on Sundays or nights, and during light load periods. You will appreciate that the magnetic energy being

stored in a generating system during the light load periods, is of a small order and not so detrimental to the opening of the arc by a breaker, as that during the heavy load periods. This was demonstrated in some of the Detroit tests.

I might add that tests on the 24,000-volt circuit breakers, and of such magnitude as conducted at Canton, are being made occasionally in Detroit at the present time. I say occasionally, and also inadvertently, if you please. Our breakers in service have been recently subjected to duty of an order as high as 700,000 kv-a. and without any damage to the breaker.

I am pleased to note that the tests were conducted with the aid of so many measuring instruments. These are very essential in obtaining reliable data, which may be used for comparison with previous results, as well as with results to be obtained in the future.

It is unfortunate that some of the data obtained in these tests are being withheld from publication. Only such data have been published as concerns directly the latest type of breaker developed from these tests. There are considerable more data covering the older types, which have an important bearing on the circuit breakers which are so extensively installed in the various systems at the present time. Operating engineers are vitally concerned in the circuit breakers in service, and should have all information in order to take advantage of any improvements which might be applied to the present equipment. This is being denied and apparently for commercial reasons.

W. L. Wallau: A year ago in Cleveland we made a few tests in a minor way. We were not equipped with oscillographs, but we had certain conditions that we wanted to meet. We wanted to see if certain switches, which were inadequate on our 11,000-volt system, might possibly be used on our 4600-volt power distribution system.

With 125,000 kv-a. connected to the generating station bus, we made tests at a substation some four miles distant. This substation was supplied by seven No. 4/0 cables operating in parallel, and the 4600-volt system for test purposes was supplied by three 3000-kv-a. stepdown banks. The switches themselves were connected to the secondary side of these banks in parallel through about 90 feet of 0000 cable. The load on the station, was about one-third of the generator capacity. These tests were carried out successfully without any undue disturbances on the system. The only trouble that developed was a ground on one cable, which was a self-healing puncture.

What prompted us to make the test was that we had this same condition to meet inadvertently whenever a short circuit occurred on one of our 4600-volt power lines, close to the substation. Why should we not try to learn something from tests? We did learn that the particular switch that we wanted to use was inadequate even for a 4600-volt service. That was due to the larger current which it had to interrupt due to transformation ratio, as compared with the manufacturer's rating at that voltage.

The actual initial short-circuit current was of the order of about 15,000 amperes, and several types of switches were tested, and among them one switch with a very light mechanism which operated very speedily, and that switch stood up better than the others and we were able to repeat a short circuit on that particular switch with four banks of transformers, giving about 18,000 amperes initially.

I think, perhaps, all of us have been a little too conservative in offering our systems for experimental work, too much afraid of what was going to happen to the system. If we start to analyze our own conditions, we will see in our occasional short circuit that we have just as severe conditions as you would meet with on test. We may have a short circuit, which possibly results in a wrecked switch, but we do not wreck all the system, by any means, and do not anticipate we will wreck the system every time we have a short.

In this particular system, on the 11,000-volt bus, it is possible in almost any substation to get an energy supply on short circuit in the neighborhood of half a million kv-a., and as we operate our transmission cables to substations entirely in parallel, it puts a very heavy duty on any of the breakers, and the substation breakers may open under reverse power to clear a fault in the cable fed by seven, eight, ten or even twelve lines.

I want to emphasize Mr. Meyer's point, the papers have not told us much about the troubles experienced. After all, the troubles are what we are interested in mostly, as much as the optimistic results which the manufacturers feel they can obtain later.

Another thing we are interested in knowing is what can we do with the breakers on our systems to modify them so that they can be used where we want them. In the past I have had occasion to report a large number of failures on the G. E. K-12 breaker, and I would like to say the failures reported were not in the nature of criticisms. We knew that the breakers were inadequate for the work they had to do, and we reported that to show how successful they had been in interrupting currents in excess of rating.

A. H. Sweetnam: It would seem to us that no operator could consider an oil circuit breaker, especially if it be on a one or limited shot basis, unless it be with the understanding that the duty cycle be "open, closed and open," as the breaker might at any time be required to close on a faulty line. One large operating company serving certain sparsely settled territory finds it necessary to operate, non-attended substations supplying from 1 to 2 distribution circuits. The transmission lines supplying such substations are fed from an attended substation bus and are equipped with automatic oil circuit breakers which will function in case of faults up to or beyond the non-attended substation. In such cases it is the practise after the automatic transmission line breaker has functioned to reclose it and if it again opens to reclose a second time, after which it is left open until the fault has been located. This plan makes possible the serving of business which otherwise could not be signed on account of high operating costs.

Many lines are radially operated, certain lines being normally in service and others held in reserve. We believe that many operating companies find it necessary to try a line by reclosing after the breaker has opened automatically and this appears to be a case parallel to that cited above; hence our conclusion that the duty cycle be defined as "open, closed, open," as any other definition would require the installation of a breaker designed for heavier duty and consequent greatly increased cost.

A. H. Hull: As you know the Queenston plant now being built will contain five 45,000-kv-a. units. When we started the short-circuit studies, we were contemplating an installation of nine such units. On that basis we estimated we would have on the 12,000-volt circuits, in the case of a fault, approximately 70,000 r. m. s. amperes and in the case of a fault on the high-voltage circuit, approximately 6700 r. m. s. amperes, at 110,000 volts.

I believe that the requirements for circuit breakers for that service are considerably in advance of installations that have been made in hydroelectric power plants. We bought two types of breakers for the 12,000-volt circuits, the Canadian Westinghouse Company's type C-4 and Canadian General Electric Company's type F. H. D. 21-Y.

While it is not anticipated that we will operate with nine units in parallel, there may be times in switching operations on the system when it may be necessary to operate eight or nine units in parallel for a short time. We have not had the opportunity of making short-circuit tests on the system, and we have been rather hesitant about accepting the ratings that have been put on the rupturing capacity of the breakers. We hope in the course of the operation of the plant to get experience with both types of low-tension breakers, that will give us, at least, comparative results, and results from which we can extend the station as now contemplated with considerably larger generating units.

One feature in connection with these breakers, which we considered very important, was strong tanks. Those on the 110,000-

volt breakers that are installed are required to stand an internal hydrostatic pressure, with the bushings and cover in place of 250 lbs., per sq. in. The Westinghouse type C-4 breaker tanks are required to stand a pressure of 500 lbs. per sq. in. They have 36-in. diameter tanks. I would like to know from the tests reported from Baltimore, just what pressures were obtained in the tanks on these tests. We have a reference in the paper to the fact that pressure tests were made, and a statement that the pressure approximated one-third of the hydrostatic pressure, for which the structure was designed. That does not tell us very much.

Another feature on which I think we ought to get further information is how the breakers will take care of phase to neutral short circuits.

At Queenston, we are operating now with the generator neutrals solidly grounded. We have had no shorts there,but have had other cases where we had shorts to neutral, and also cases where we had metallic three-phase shorts on which the breaker has been closed. I think further information on the question of phase to neutral shorts is desirable.

A. F. Bang: In connection with the Baltimore oil switch, I would like to point out a few operating features which have a very distinct bearing on the performance of breakers. I refer particularly to the influence of the relay setting, the influence

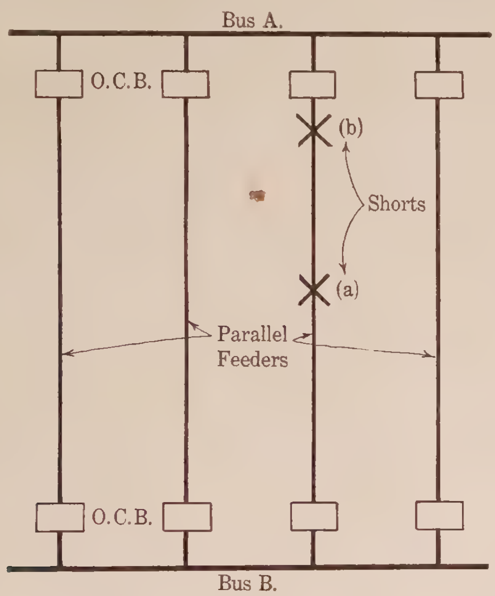

Fig. 1—Single Wire Diagram of Parallel Feeders

of having parallel feeders, and the influence of the arc in an arcing short. I think it is well to call attention to these operating conditions, so that we can realize that at least as far as opening a short circuit the Baltimore tests were actually extremely severe. I think too if we consider these facts, that to some extent they will explain why we actually have been able to get along fairly well for so many years with breakers which we knew were not quite up to the rupturing capacity of the system which we were dealing with.

I will dwell first on the influence of the time element. In most power systems the minimum time of relay operation is about one-quarter of a second, and in many cases that time element is increased the closer you get to the generating station. That, of course, means that where you get the highest current you have the longest time. That is not done intentionally for easing the task of the breaker, but simply in order to secure selective relay action. Incidentally, it means though an easier switching task for the breaker for several reasons. In the first place, a dead short circuit usually begins with a very heavy value and then gradually dies down, due to the demagnetizing of the generators. In some systems the current in one second may perhaps die down to one-half value. And for the same reason—that is, the demagnetization of the generators—the voltage which will establish itself across the switch contacts, at the moment the arc is broken, will be proportionally reduced. That means only one-quarter of the rupturing task for the switch which you would have had if the breaker tested opened at the first instant.

There is a third item which comes in. If you delay the opening up of the breaker, it is possible that some of the synchronizing equipment may fall out of step. If that happens, that will draw some of the current away from the short, and will keep the voltage down, while the breaker is opening. That, too, means a reduced switch duty. In some cases it is quite possible that the synchronous equipment, which was out of step, may be pulled into step again *after* the breaker has opened up, and when you come to look at it, you cannot understand how a small breaker seemingly successfully broke an enormous amount of current. The fact is that it was favored extremely by circumstances.

Now as to the influence of parallel feeders: These tests in Baltimore were all made on a radial feeder. In many cases we do not have such a condition, but are dealing with a number of parallel feeders, each connected through to a station bus. If a short circuit takes place on one of these feeders it is clear that none of the breakers *A* or *B* (see Fig. 1) will be called upon to interrupt the full amount of the current, but it will be divided in some way between them. If the short is approximately midway between the two stations and the two breakers should happen to open at exactly the same time, evidently each breaker will have only ½ of the current to break. If on the other hand, the short is close to one end of a breaker it is true that the greater current will pass through this breaker and with relays of the time characteristics ordinarily used in such cases, this breaker will open first and break a very heavy current, but as the short still remains on the system, the voltage will still remain low, and not reestablish itself before the second breaker at the other end opens. In other words, the first breaker will rupture a very heavy current but low voltage, and the second breaker will break a higher voltage, but a current considerably reduced by the insertion of the length of the feeder. Under both assumptions we find thus a division and reduction of the switching task.

To my mind the Baltimore tests were also especially severe because they were dead metallic shorts, just as Mr. Jamieson pointed out. If you have an arcing short as you will get both on overhead lines and underground cables, the conditions must be less stable, because you have three arcs in series in that case, one at the short and two in the oil switch. Probably this feature is of more importance when you are dealing with lighter short circuits, where the arcs generally are less stable than when you are dealing with very heavy ones. In Baltimore we still expect to look further into that particular phase of the question, and also some of these questions regarding the influence of paralleling of lines and delayed time settings.

E. R. Stauffacher: These short-circuit tests are indeed interesting to us. We, in the West, are approaching the conditions of the central stations in the East in a number of territories. The main difference, however, is that our operating voltage is much higher.

You have been speaking of interrupting capacities of 500,000 kv-a. and 650,000 kv-a. From some of the results we have had in our stations and from the calculations we have made, the amount of current that certain switches on the system of the Southern California Edison company must interrupt is fully as great.

At our Newmark substation, located near Los Angeles, four 66-kv. double-circuit transmission lines feeding from four different points are brought to a common bus. It has been calculated that there are approximately 6000 amperes flowing at the time of a short circuit on this bus. A few cases have occurred where disastrous results have justified the calculation. It appears as if our 60-kv. network system must, some day, be changed to a 110-kv. system. At the present time both of our 150,000-volt

transmission lines are being changed. We are raising the towers and adding insulators and shield rings so that we expect to be operating at 220-kv. by the latter part of this year.

Oil circuit breakers for voltages as high as 220 kv. are somewhat of an experiment. The manufacturers have been very kind in furnishing their best talent and in giving us the latest engineering information on this subject. We are waiting with interest the results of breaking a short circuit of approximately 2000 amperes at 220 kv. which will be the condition on our Big Creek transmission line, for if the switches do not handle the situation it will be quite a serious matter. This condition, that of the use of higher voltage circuit breakers, appears to be the greatest difference between our Pacific Coast and the eastern application of oil circuit breakers.

F. C. Hanker: In recent years, the importance of mechanical strength of structure has been fully recognized, the most important advance in that phase of design resulting from a similar series of tests made in New York and reported to the Institute. These tests differed from the present series in that they were for the purpose of establishing the mechanical sufficiency of the structure under the magnetic stresses resulting from heavy current conditions. The modifications made, following the New York series of tests, have been embodied in the later designs and it is of interest that the types used in the Baltimore series showed no distress from this point.

The oil circuit breaker tests at Baltimore have re-assured the operating companies as to possible hazard from making such tests and they realize that it is essentially a duplication of their operating condition. We trust that in the future other operators will take advantage of the results of these experiments. I was interested in reviewing the field tests that has been made in the past. Mr. Meyer referred to one on the Detroit Edison System in 1915. The test on the Niagara Falls System across the river probably represented the next highest capacity concentrated. This test was made in 1911 and was with from one-quarter and one-fifth of the capacity used at Baltimore. Previous to that, we had tests on machines of single units, isolated on separate bus sections of 11,000 and 12,000 and up to 30,000 kw. concentrated. Some of the tests made across the river on the hydroelectric plant had the cable system connected and in effect were similar to the Baltimore tests except in magnitude.

As Mr. Meyer pointed out, those at Detroit gave essentially the same concentration of power, the only difference being that they were not as extensive as the Baltimore tests. At Baltimore, they had on the order of 170,000 kw. connected. The short-circuit current was limited, as Mr. Louis indicates, by series impedance in order to give the desired values at the Canton substation.

Mr. Meyer mentioned the amount of magnetic energy in the machines. As a matter of fact, that has considerable bearing on the restoration of voltage, but the flux condition in the machine must be the same with the same induced voltage. This is clearly demonstrated in the values of reestablished voltage that were on the order of 80 to 90 per cent of the system voltage. The number of high power tests will probably be limited to a few large systems, and they will certainly be increasing when you consider the amount of interconnection.

Distinct developments have resulted from each series of tests that have been made in the past on systems of operating companies where conditions the same as those obtained under actual operation are found. In the present instance, the changes have been of a minor character, proving that the fundamental principles are correct. Fortunately, sufficient time was available to test the modified structures to definitely prove the correctness of the improvements.

It is difficult to obtain from papers that have been presented an adequate conception of the magnitude of the work that has been done and of its importance to the industry, especially when you consider that the fundamentals of the designs have been unchanged. It is particularly important that the adequacy of the breaker structure has been confirmed. When you consider, the enormous energy that may be concentrated in an abnormal, the necessity for having a structure that has a large factor of safety in rupturing capacity and mechanical strength to meet the most severe conditions is fully recognized.

In recent years, there has not only been an increasing growth in the size of power stations but a marked increase in the total capacity of systems resulting from interconnections. The advantages from unified operation are so well established that there will be an increase in the total system capacities, making it essential to have adequate interrupting devices to insure continuity of service.

As a result of the uncertainty that has existed in the past, as to the adequacy of the very large circuit breaker structures on moderate voltage systems that are installed indoors, there has been a tendency to consider designs of structures to provide against the possibility of failures in the circuit breaker parts that might cause breakdowns on adjoining circuits. These studies have resulted in two notable examples using the so-called segregated phase layout. At present there are several stations under construction or being designed where careful study has been given to the advantages and disadvantages of the latter schemes. It would be very valuable for the Institute to have the benefit of the conclusions that have been arrived at by the various engineers.

The sufficiency of the breaker structure has been clearly demonstrated in the Baltimore tests and it will be of interest to determine whether operating engineers consider it necessary to resort to phase segregation in order to provide against a spreading of trouble to adjacent circuits by complete separation. The other parts to be considered are the bus structure, the disconnecting switches and the current transformers. A number of failures have resulted from faulty operation of the disconnecting switches and it is necessary that designs should embody features that will overcome such difficulties. In recent installations where switches are mechanically operated and interlocked with the breaker mechanism this should be sufficient precaution against such failure.

In the last few years there has been considerable criticism of the standard rating adopted for circuit breakers following the presentation of the problem in 1918 at the Mid Winter Convention. It is to be hoped that a full discussion is secured so that the requirements of operating companies can be crystallized and ratings be standardized for a minimum number of conditions. In past discussions, it has been difficult for the operators to agree on the ratings necessary to meet the varied conditions of operation for different classes of service. It is to be hoped that the discussions at the present sessions will clarify this situation.

H. H. Dewey: Tests of oil circuit breakers have been made from time to time that have been valuable in giving the manufacturers data on which to base their designs, but often these tests have been so limited as to the amount of energy in the short circuit or the completeness of the data recorded as to leave opportunities for differences of opinion on the interpretation of the results. The tests described lack none of these features and we may well feel that a most important step has been taken toward the ultimate solution of this most important phase in the development of our large power systems.

It seems like heroic methods to subject a power system of 150,000 kw. capacity to a succession of heavy short circuits, but the results of this investigation show that it can be done without serious risk to apparatus or service if done systematically and with due regard to the protection of the system from secondary failures. I have no doubt that other operating companies will be less hesitant in making similar tests in the future.

One of the most gratifying results of the tests, it seems to me, is the indication that the manufacturers have not been so far wrong in their ratings of switches of standard design. Practi-

cally all of the switches tested performed well and only slight modifications were necessary to show most satisfactory results.

The rapid growth in the generating capacity of our power systems has put the problem of the selection of oil circuit breakers squarely up to the electrical industry and the greatest difficulty has been encountered in keeping up with the growth of these systems. There are undoubtedly thousands of switches in service today that would fail if a dead short circuit should occur at their terminals. Operating companies are replacing these switches as rapidly as possible, but physical limitations and the expense involved render this necessarily a slow process. It is surprising that as few of these oil circuit breakers have blown up, with disastrous results, as have, but the answer is, doubtless, that the short circuits have not occurred. Some of the reasons why they have not occurred were brought out by Mr. Bang; such as, the fact that not all short circuits are of full theoretical value, the recovery voltage is not always complete, systems may normally be partly segregated, etc.

We are gradually growing to the point where greater and greater short circuits are being imposed on our systems and it is becoming increasingly important that study be given to the initial layout of the system connections, not only so arranging the circuits as to take full advantage of the neutral reactance of apparatus and connecting lines but by judicial use of reactors to keep the short-circuit values to the lowest practical value consistent with good operation.

The tests under discussion showed short-circuit values of the order of one-half million kv-a. There are several systems now operating that may be subjected to short circuits of this value or more and many being designed that will reach a million or a million and one-half kv-a. Oil circuit breakers designed to safely interrupt such values as these must necessarily be large and expensive and the economic problem is becoming a most important one.

The question was raised by Mr. Jamieson and Mr. Meyer, as to the best way of dealing with the problem of old circuit breakers that have been outgrown due to increase of system capacity. This question has been partially answered by both manufacturers by the evidence from the tests that they can materially increase the rupturing capacity of their switches by comparatively inexpensive changes. Where the increase in the required interrupting capacity is great, however, the problem is a very difficult one.

Mr. Jamieson called attention to the desirability of settling on a duty cycle to be used as a standard in selecting oil circuit breakers. The N. E. L. A. and other technical bodies have this matter under active consideration and the difficulties are gradually being clarified. It is hoped that an analysis of the Baltimore test results will throw some further light on the matter and an early settlement may be made.

I hope that as time goes on, we will see further tests similar to those made at Baltimore where elaborate preparations were made to obtain definite and accurate data. Such tests are of inestimable value and the very fact that some 200 short circuits were placed on the system without serious damage to apparatus or service, should lead to further tests of this kind.

M. J. Lowenberg: I have witnessed several cases where oil circuit breakers were closed on a three-phase dead short circuit, in one case at the bus two minutes apart on a system having at the time over 220,000 kw. in generators running and where the breakers functioned successfully without disturbing any synchronous apparatus or service.

Some one asked what we are to do with our old breakers. I think that what we should do is to maintain and inspect them especially after a very heavy duty. It does not cost much to produce very good results in this way. The Interborough Rapid Transit Company have some old type *H* breakers on a system of anywhere from 250,000 to 300,000-kw. generator capacity on the busses with a like amount of synchronous converters, where they have had very heavy short circuits that were cleared in every case with no serious trouble to the breakers or equipment. This performance is due not only to the character of the breakers but also to the rigid inspection and maintenance of the breakers.

I would like also to call the attention of the manufacturer to breakers (on systems of less than 6600 volts) which should have a better balance than they now have between heating capacity and rupturing capacity. Take for example a breaker operating at 2300 volts. You will find the breaker is limited by heating capacity and not by rupturing capacity.

L. B. Chubbuck: Referring to the oil separator described by Mr. MacNeill it may be of interest to state that separators of this type are furnished with the tank type 12,000-volt breakers at Queenston. One separator 8-inch diameter by 13 inches high is used per pole, the exhaust from the separator to be connected to station vent pipes, to prevent accumulation of gas in the circuit breaker rooms. It is our experience that without such separators, low-tension breakers under severe service, are liable to blow gaskets or throw excessive oil with ordinary vents. Tank structures can be furnished of sufficient strength to meet the arc gas pressures corresponding to the breaker rating. High-speed operation, properly designed and submerged contacts, strong, non-fragile bushings and arc-proof insulating tank linings, are also important factors. The Queenston tank structures are designed for an ultimate strength of 1000 lb. per sq. in. internal pressure and the condenser bushings to meet a cantilever test of 5000 lb. applied at either end of bushing.

We have had a number of instances in Canada of breakers failing, not due to pressure from arc gases, but from gas explosion above the oil. Such failure is not possible with the larger, later designed low-tension breakers, owing to the tank structure strength required to meet their rupturing capacity. However in the case of high-tension breakers we find possible gas explosions the chief hazard to the strength of the breaker, and for this reason furnished the Queenston high-tension breaker tanks of an ultimate strength equivalent to 500 lb. per sq. in. internal pressure.

O. H. Eschholz: Breaker distress has been shown in these tests to be primarily a function of arc energy and the character of arc gas control. While the rupture duty, I wish to call your attention to, of direct-current circuits is dependent upon the formation of an unstable arc, the interruption of the alternating-current circuit requires the prevention of arc reestablishment after zero current has been reached. The former necessitates a continuous increase in arc resistance; the latter an exceedingly rapid change from a medium of low to one of high dielectric strength.

An inspection of the current waves in the various oscillograms secured reveals the important fact that the arc current changes but little during the rupture period. To minimize arc energy and hence breaker distress it is therefore necessary to maintain a low-voltage arc and to decrease arc duration. Various expedients may be adopted, either in the construction of arcing contacts or in the control of pressure variations of the arc enclosing medium, to assure a low arc voltage during current flow. Obviously, a decrease in energy development decreases gas evolution and hence simplifies the problem of preventing arc reignition. It may be of interest in this connection to note that with some of the constructions adopted it was possible to consistently restrict arc duration to one-half cycle when rupturing currents of the order of 20,000 amperes. While of no practical need at the present time, it is interesting to know that by properly choosing the instant of arcing contact separation, the arc durations when interrupting large currents, could be reduced to one-quarter cycle. In such cases it was difficult for observers to distinguish between the character of breaker disturbance when opening on a heavy short or on a dead line.

It is well known that the formation of an arc in a liquid requires first the disintegration of such liquid into its elemental gases. During the subsequent period of arc maintenance, the developed energy must be absorbed by the surrounding me-

dium—a part of this energy causing the continued cracking or disintegration of the oil. During the period of gas development the breaker is subjected to transient hydrostatic pressure waves, dependent upon rate of gas generation and escapes, as well as to somewhat more sustained pressure resulting from gas accumulation and possible ignition in the air space. By reducing the rate of arc energy development, the hydrostatic pressure was decreased and by selectively venting the air space gases in advance of the arc gases, the sustained and ignition pressures were practically eliminated. In the conventional type of dead tank breaker, it is possible to utilize the movement of oil head above the arc gases as a piston to eject the cushioning air space gases. By directing these gases into a suitable separating chamber, it is possible to relieve the breaker rapidly of gas accumulation while preventing an escape of oil and simultaneously permitting cooling of the arc gases below the ignition temperature.

The development of information on other, though less important characteristics may be mentioned such as the effect of catalysts on lowering the ignition temperature of arc gases, variation of arc duration with oil viscosity and the volume of gas generated per kw.-sec. of arc energy for different oils. Such information in conjunction with a better conception of the mechanism of arc rupture not only has contributed to the successful conclusion of these high-current tests but offers a basis for the scientific development of circuit breaker structures of all ratings.

J. D. Hilliard: Mr. B. G. Jamieson in his discussion of the oil circuit breaker papers brings out the importance of the duty cycle in the rating of oil circuit breakers and also the importance of the method of making the tests to determine such rating. Neither of these points has heretofore been discussed to the extent that their importance merits. As a general proposition, all tests of oil circuit breakers should be made under as nearly as possible the identical conditions the breakers are to be subjected to in service. If the breaker is to close under a condition of existing short circuit, then by all means it should be tested under that condition. If the breaker is to be installed where it will have to close and open a short circuit close to the bus bars (zero power factor) then it should be tested under that condition.

If the breaker is to be installed on a system with the neutral either grounded solidly, grounded through a resistance, or ungrounded, then it should be tested under such conditions and in addition *with* and *without* a ground at the point of breakdown. It should be tested with the same operating mechanism which is to operate it in service. If the breaker tested under a particular set of conditions is found to have a certain interrupting capacity, do not assume that under all other conditions it will have the same interrupting capacity because you will be deceiving yourself. If you have made a few shots under a certain set of conditions, you cannot assume that the tests, if continued, will uniformly give the same results. The plot of a set of observations made upon the ordinary oil circuit breaker from low currents up to its maximum rating but under otherwise identical conditions looks like the shot gun pattern of a cylinder bore gun or blunderbus. Certifying to bull's-eyes from such a target is a difficult proposition and besides it is not the bull's-eyes you are after, but the scattered shots on the fringe of the pattern because they represent the spots of maximum gas formation in the breaker and therefore the maximum stresses on the breaker structure.

The foregoing indicates the difficulty of giving an interrupting capacity rating to the ordinary oil circuit breaker. The only absolutely safe thing to do is to specify the rating under the worst possible condition which may exist. It must be expected, however, when such ratings are demanded that the costs will correspond, because the costs of the breaker under the different standards of rating do not change.

Mr. Jamieson draws attention to my italicized statement in the paper. That italicized statement is of considerable importance and was made with a fairly good idea of what the results would have been if conditions had been different; conditions which might easily exist in actual operation of the system, and which might give results much more severe than those observed.

The differential rating of oil circuit breakers operating at 25 and 60 cycles is a debatable question at least to the extent of the ratio of the two frequencies. The time-ampere curve at any frequency is at first ascending, reaches a maximum and then descends with the continual increase of current. The effect noted is due to the inherent blowout effect of the breaker as ordinarily constructed and the fact that several half cycles are required before interruption, the number gradually decreasing with the increase of current is a definite proof that *time*, not half cycles, is the limitation and that the *time* at 60 cycles would be substantially the same as at 25. With the increase of current to a value where one full half cycle is the limit at 25 cycles, then a further increase of current should correspondingly decrease the actual time duration of arc at 60 cycles to less than at 25 cycles, but the magnitude of current required would be such as could be obtained from few generating systems and with an increase of the voltage of the system one would expect the current necessary to interrupt in one-half period to correspondingly increase and it might well be that the actual time limitation would be the break distance between moving and stationary contacts instead of the electro-magnetic blowout effect of the current to be interrupted because the ultimate interruption depends upon the dielectric strength of the medium between the separated electrodes.

The recovery voltage at interruption, together with the phase relation between current and voltage, undoubtedly largely determine the interrupting capacity of the breaker and a study of these recovery voltages under different conditions of operation supply an explanation of many hitherto puzzling phenomena in connection with oil circuit breaker operation. Mr. Meyer notes that most all tests are made either on Sundays or nights after the peak load is over and suspects that the results of tests under these conditions might be different than if they were made under more normal operation conditions. I agree with Mr. Meyer in this belief and think that more tests should be made under normal conditions.

Mr. Wallau's testing experience at Cleveland is not unusual. Certain well recognized factors contributed to the results obtained, and with these factors reversed, the results would have been reversed. It is one more case showing the necessity of making the test conditions the same as the operating conditions.

The General Electric Company did not test any breakers at Baltimore, other than the H-3 and H-6 breakers and the improvements thereon, principally the improvements, because the end sought was to obtain a breaker which would stand repeated short circuits, and this boiled down to obtaining ones which would not throw oil because the inherent interrupting capacity of the old breakers was found to be ample, but the oil throwing property was well known and acknowledged by all. The development was successful and the remodeled breakers are installed in the same cells as the older oil throwing type.

J. B. MacNeill: I wish to state the position of the manufacturers in publishing data on these tests. There had been a feeling that these tests were of a more or less confidential nature, the same as factory tests would be on other lines of apparatus except that when powers such as here used, are employed, factory tests cannot be considered. The feeling was expressed by several operating companies that a large number of new stations were to be built in the near future and that data should be published which would allow the operators to select adequate circuit breakers for such new developments. It is not proper to judge obsolete circuit breakers in many cases by results obtained in Baltimore as these tests were made under the hardest possible conditions obtainable so far as circuit breaker performance is concerned.

Mr. Bang gave in his discussion some of these conditions and he speaks from a full knowledge of this subject as he has done experimental work along these lines.

Mr. Jamieson calls attention to the difference of opinion regarding the duty caused by closing the breaker on the short circuit. The writer did not intend to convey the idea that closing on the short circuit was a negligible matter, but with the type of breaker he was discussing, it seems that the duty of closing on short circuit is relatively light to the duty of opening on short circuit. It is appreciated that the duty of closing of short circuit may differ widely with different breaker constructions.

In connection with Mr. Jamieson's remarks on the duty cycle it should be pointed out that the manufacturers are willing to rate their apparatus on any duty cycle to which the operators as a whole will agree.

Undoubtedly the ratings on duty cycles which involve closing against heavy short circuits will be lower than if the duty involved merely opening the short circuit.

The Electric Power Club has indicated that the ratings of breakers to close against and open short circuits with the more stringent specifications regarding the condition of breaker after test referred to by Mr. Jamieson, will be approximately the same as the ratings which have been given in the past on the so called "two-shot" duty cycle in which the breaker opened the first short circuit and was closed against and opened the second short circuit. This means approximately a de-rating of 20 per cent from present values.

Regarding Mr. Jamieson's comments on repeated closing of heavy short circuits we agree that it is undesirable from an operating point of view to subject systems to repeated shocks. The "five-shot" specifications insisted on by Baltimore Companies was made in view of their experience that imperfections of construction can be disclosed by such a test and that the removal of these imperfections results in superior breakers for any duty cycle; thus, a breaker which will open 20,000 amperes satisfactory 5 times or as was the case in one of the breaker tests, 12 times, undoubtedly has a large factor of safety over 20,000 amperes for less severe duty cycles.

Mr. Meyer refers to tests made by his company on the same general form of breaker covered by the writer in his paper. These tests were of power magnitude comparable with the Baltimore tests and differed principally in that they were not the repeated openings of the short circuits without inspection of the contacts or oil.

The Detroit tests remain to the present time the most important tests that have been made on 24,000-volt circuits.

Mr. A. F. Bang's discussion should be of great interest to operating men, especially as Mr. Bang discusses the possibility of retaining in service by proper system connections, breakers which otherwise would not be serviceable.

The discussion of Mr. O. H. Eshholz is important as he deals with some of the theoretical factors regarding important improvements in construction which were first made possible and later proved out by the Baltimore tests. These tests have allowed us for the first time to study in detail at high powers the exact action of the circuit breakers on short circuit with the aid of complete facilities for analysis. The two operating companies participating in this test, the Pennsylvania Water and Power Company and Consolidated Gas, Electric Light and Power Company of Baltimore have been very patient in allowing the revision of circuit breaker constructions during the course of the tests, and subsequent proving out of alterations. By this method, important results have been secured and it is possible to speak with authority of many features of breaker construction that otherwise would still be in a speculative stage.

Designers of circuit breakers therefore now have a solid foundation of fundamentals to work on so that better distribution of material in designing is possible and increasing rupturing capacity can be had from a given amount of material.

Transmission Line Relays—II

BY E. A. HESTER, R. N. CONWELL, O. C. TRAVER and L. N. CRICHTON

(Concluded from page 852 of JOURNAL for November)

III. Differential Power Schemes. The differential current schemes just described, though usually simple in equipment and installation are subject in some cases to disdavantage in that the line in trouble does not carry the greater current. Differential power protective schemes for parallel lines, however, are discriminating in their action in all cases and can be relied upon when the effectiveness of the simpler schemes may be doubtful.

A Modification of the Differential Power Scheme

One company reports the installation of the fundamental scheme described in the paper on Transmission Line Relay Protection in 1919, but the application has been modified by the introduction of auxiliary transformers across the secondaries of the current transformers. These are used first as balancing transformers, different ratios being provided so that differences in the main current transformer secondary currents may be compensated for; second, to permit grounding of the main current transformer secondaries without danger of interference with the operation of the relays; and third, under heavy short circuits the auxiliary transformers become saturated and limit the current flowing to the relays, thus preventing the tendency of the relays to "chatter".

In this installation elaborate arrangements have been made to substitute plain over-current for the differential power protection when operating changes require and provision has been made, by means of a differential direct-current relay and contactors arranged as a bridge, automatically to open the current transformer loop when only one line is in service, thus leaving plain directional protection on the line.

No operating results for this installation were supplied and it is described chiefly as an interesting modification of a well-known scheme.

Differential Duo-Directional Relay Schemes

Several companies reported installations of differential duo-directional relays. A simplified diagram of this scheme is shown in Fig. 13. No special equipment is required, standard over-current and directional relays, with double-throw contacts on the directional element,

being used. The principle of operation of the scheme is the same as that described in the paper on Transmission Line Relay Protection in 1919.

It may also be well to point out that if protection against balanced or bus faults is desired, over-current relays may be inserted in each current transformer secondary circuit to take care of such requirements.

Outside of the usual phasing tests as made in the standard uni-directional relay installation, there are no special precautions necessary except to make a check for zero current by inserting a low-reading ammeter in series with the relay current coil while the lines are heavily loaded.

One company reported two trial installations of these relays which were installed because of a desire to find a balanced scheme, applicable to two lines which would not require tapered settings for selectivity and would not be affected by through short circuits.

Installation No. 1 has been in service since April 1919. Up to June 1921, there were twenty-five operations, two of which were correct and twenty-three faulty.

Of the two correct operations, one occurred during a sleet storm, one line being out of service. The other opened at both ends and two phases were found to be faulty. No other lines came out, and although classed

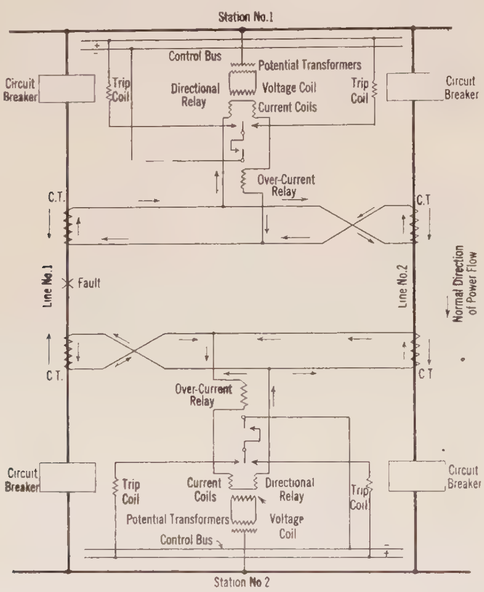

Fig. 13—Schematic Diagram of Differential Duo-Directional Scheme

as a correct operation it is not a fair trial of the scheme as applied to paired line protection. The other correct operation occurred during an electrical storm.

Of the twenty-three faulty operations, nine occurred during electric storms. Of these, eight opened both lines and other lines were opened on the same disturbance, and one opened only one line, the other being out of service at the time, but other lines on the system were opened. Of the remaining fourteen operations, there were three cases where both lines were opened but no others, and eleven cases where both lines were opened with others.

Installation No. 2 was put into service in July 1919 and up to July 1921 there were twelve operations, three being correct and nine faulty.

In one of the three correct operations one of the paired lines was out of service at the time so the operation was similar to that of installation No. 1. In another operation faults occurred on both lines and both were cleared. The third operation was the only case of a fault occurring on one line of the pair, in which the faulty line was cleared and the healthy line remained in service.

Of the nine faulty operations, two occurred during electric storms. No cause was found but both lines were opened and other lines were opened in one of these cases. Of the remaining seven operations both lines were tripped out and in three of these cases other lines were also opened.

The results obtained from the operation of these trial installations, up to June 1921, were not satisfactory. There seemed to be a greater tendency for the relays to operate on through short circuits and during electric storms than with the standard directional scheme using two relays. It was desired, however, to give the installations a further trial. It was thought that the wattmeter element to which the double contacts are attached, having less than one-sixteenth inch movement from one contact position to the other, upon clearing the faulty line rebounds from one contact to the other and thus trips out the healthy line. It was, therefore, decided to install locking relays which would make inoperative, for a definite time, the oil circuit breaker trip on one line when the relays are actuated to trip the other line of the pair. In this way it was hoped to overcome the difficulty.

These locking relays were put in service on installation No. 1 in June 1921, and up to March 1922 there were nine operations, six of which were satisfactory and three faulty. Of the six correct operations two occurred during storms and four were due to flashovers. Of the three faulty operations, one occurred during an electrical storm, with one line of the pair out of service, a fault on another line caused the remaining line of the pair to trip out. In another case both lines tripped out when one line was tried out after a correct operation which was due to operating conditions and not the fault of the relay. In the third case an end fault on one line tripped both lines out. The relays have been reset for this end fault condition.

On installation No. 2 the locking relays were put into service in July 1921 and to March 1922 there has been one operation. This occurred during an electric storm and was satisfactory.

From these last operating results it would seem that the locking relays have, to a large extent, overcome the difficulties originally experienced. It is intended, therefore, to retain both installations and give them further trial.

Except in the matter of lessened panel space and the slightly smaller investment required for the duo-

directional equipment over the double unidirectional equipment, this company considers that the trial installations have shown no advantage.

Another company reports the installation of nine groups of these duo-directional relays. Locking relays are not used on any of these installations and the operating records show that over a period of fifteen months after they were put into service, the operation was correct in about 70 per cent of the cases of trouble. These results were not considered entirely satisfactory but the installations are to be retained with the intention of further improving them.

A third company reported the installation of eleven sets of these relays which were originally installed without locking relays, but these are now being added. Although operating records were not available to show successful and faulty operations, the equipment is reported as having proved satisfactory. A number of difficulties has been encountered but all were not attributed to causes inherent in relays but to external faults such as defects in wiring and burnouts.

A fourth company reports the use of two groups of these relays but no definite operating records were given so that it was not possible to determine whether the installation was satisfactory.

The fifth reported that four groups of these relays were in use but the operating results as given were not sufficiently definite to determine what success had been obtained.

Differential Power Scheme Using Bus Section Circuit Breaker

One power company reports the use of a bus-section circuit breaker tripped by over-current relays to provide protection in case of a bus or other balanced fault. An auxiliary switch then serves to inject additional time when this section circuit breaker opens, practically resulting in time over-current and directional protection until the circuits are again paralleled by the section circuit breaker.

Except in the case of balanced faults the conventional differential power scheme is used and the method of sectionalizing the bus has the advantage of maintaining service over one line and on approximately one-half the feeders in the station in case of bus failure.

IV. Ground Relay Schemes. When a system neutral is grounded through a comparatively high resistance the usual over-current relay set for short-circuit protection may not be able to operate in case of ground faults. It appears to be accepted practise in such instances to connect a "residual" relay in the neutral lead of the current transformer secondaries. This relay will be energized only in case of a ground on the system and accordingly may be set for a very much lower value than the "phase" relays. These residual relays may be given time and current grading in the same manner as the phase relays. The general practise is to use phase relays in each of the three phases and the residual relay in the neutral. This is recommended on account of the fact that the third phase relay provides added insurance of protection in case of either phase short circuits or faults to ground.

Pilot Wire Protection against Grounds

On a 23,000-volt cable system looping frequently through substations and further interconnected into a network so extensive and complicated as to involve rather high and difficult settings, the pilot wire protective scheme shown in Fig. 14 has been installed in five of the shorter sections with a sixth now being added.

From the diagram it will be noted that the protective equipment is connected to the neutral circuit of the main current transformers and that practically no current will flow in any of the tertiary circuits under normal conditions or under abnormal conditions not involving a ground. This insures against any possibility of operation for overloads or for any faults which do not go to ground. This characteristic may be considered a disadvantage by some engineers but the operating company in this case feels that the proportion of faults which do not either start with, or become,

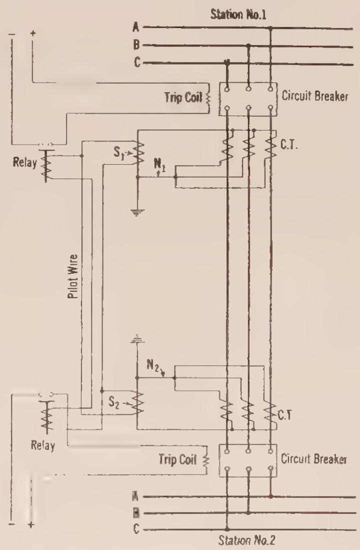

Fig. 14—Diagram Showing Scheme of Pilot Wire Protection Against Grounds

grounds is sufficiently small to justify the reduction in equipment secured and the additional safeguard against operation on through faults.

If a ground is assumed as occurring on some more remote section, equal currents will flow in the neutral circuits N_1 and N_2; secondary current transformers S_1 and S_2 connected in these circuits (principally to permit grounding of the main current transformer secondaries for safety reasons) will then cause a current to circulate through pilot wires A and B. No current flows through the relays, however, due to the use of the third pilot wire R which permits connecting this relay circuit to equal potential points regardless of the drop in the other two pilot conductors. If, on the other hand, the ground should occur on the section

under consideration there will again be currents in the neutral but in this case they will be unequal or opposed and accordingly a current approximately proportional to the fault current will flow through the relays and pilot conductor *R*. This will cause relays to operate and the circuit to be isolated.

These five sections have been in service from one to two years. During this time none of these cables have failed. Therefore positive data on the operation of this equipment are lacking. A number of artificial faults have been applied, and the relays operated correctly in every case.

The advantages of this scheme have been given above. Granting that protection against grounds is all that is required the only practical disadvantage consists in the additional cost of the third pilot wire.

Selective Ground Relay Scheme

One company reported the trial installation of a selective ground relay scheme which was adopted with the expectation that faults of slow development would be cleared at an earlier stage than is possible with phase relays, thus preventing the trouble from being communicated to nearby lines and preventing the system from being subjected to severe shock.

The installation was made on five lines and the voltage is 26,400 with the neutral solidly grounded, at the generating station.

A schematic diagram of the installation is shown in Fig. 15. It will be observed that the ground relay is connected in the neutral of the current transformer bank

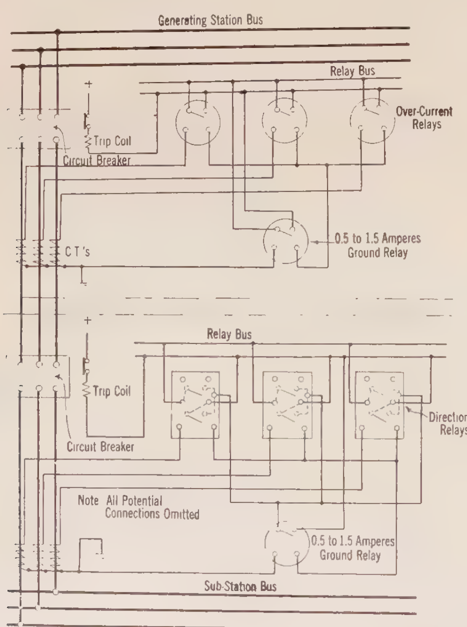

FIG. 15—DIAGRAM OF SELECTIVE GROUND RELAY SCHEME

and that where over-current relays are used their contacts are paralleled with those of the ground relays. When the over-current directional combination is used the ground relay contacts are arranged to short circuit the over-current element, thus leaving the wattmeter element to discriminate as to direction of power flow. No special equipment is necessary except that the directional relays are equipped with an extra terminal which taps the trip circuit between the contacts on the two elements.

The ground relays are induction type over-current, having gears interposed between the disk-shaft and the contacts. They have a minimum operating current

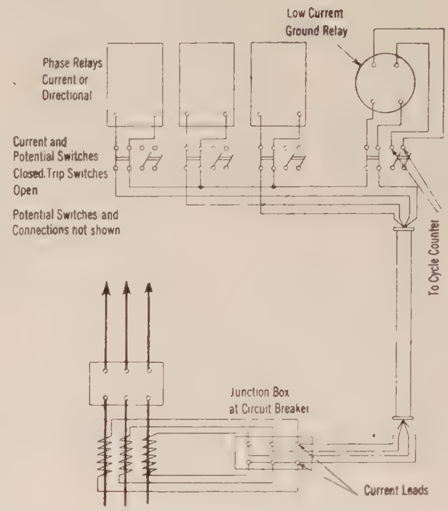

FIG. 16—METHOD OF TESTING GROUND RELAYS WHEN USED WITH BUSHING-TYPE CURRENT TRANSFORMERS

range of from 0.5 to 2.5 amperes and the energy consumed is low, being in the neighborhood of 2 to 3 volt-amperes. The current transformers are of the standard through or bushing type.

The relays are set by applying test current to the secondary terminals of one of the current transformers, with the three phase relays and the ground relays in circuit, as shown in Fig. 16. The secondary test current is determined by dividing the primary ground current by the turn ratio of the current transformers. By this method of testing, the exciting current of the current transformers and the shunting effect of the circuit formed by the two current transformers and phase relays on the other two phases are taken into consideration. With bushing-type current transformers these factors greatly modify the setting unless allowance is made by calculation or by the test method.

These installations have been in service from December 28, 1920 to the present time. Prior to January 1921 there were two correct operations both of which indicate that the ground relays operated at an early stage in the development of the fault.

Since January 1921, a 150-ohm ground resistance has been installed limiting the ground current to 100 amperes. The following summary of operations show the results which have been obtained: Up to March 1922, there were seventeen operations, four of which were faulty and thirteen correct. In the case of the faulty operations, two lines, not on the same pole line, operated upon a fault or flashover on one of these lines.

No lines were found to be bad. In July 1921, the settings were changed on these relays, and since then no faulty operations have occurred. Of the thirteen correct operations, in six cases one line only came out with no lines bad, but the dip in voltage gave evidence of a flashover. In seven cases, two lines on the same pole line opened, two cases a fault occurred on one line and one case a fault occurred on both lines, while in the other four cases no lines were found to be faulty, but a flashover was evidenced by the dip in voltage. These are counted as satisfactory operations, inasmuch as the lines are in a section frequented by strong winds. The lines are all closely spaced on the crossarms and experience has shown that in a large percentage of cases a flashover on one line carried over to the other lines.

The above summary does not include operation during electric storms. There have been three or four heavy storms in which the load dispatchers were not able to make any record of the operations.

The reporting company has since equipped another 26,400-volt system, having a 150-ohm neutral resistance with selective ground relays operating on bushing type current transformers. This system consists of four lines with widely spaced conductors arranged in a loop. No operating data for this installation are available.

Another company reports the installation of a residual relay, of the type described in the foregoing, in the neutral lead of the current transformer secondaries on a differential power scheme. These installations are at the receiving end of three sections of 110-kv. double-circuit lines in tandem. The function is exactly the same as that of the residual relay at the receiving end of the foregoing scheme. These installations have only recently gone into service and therefore no operating records are available.

Selective Differential Ground Relay Scheme

One of the companies is making use of the conventional differential power scheme, using directional relays on its high-voltage system, consisting of two parallel lines with a number of substations, sectionalizing them at various points. But in addition to the differential relays for protection against short circuits the company makes use of induction-type differential relays connected in the neutral connection of the current transformers so as to disconnect a grounded transmission line. This is necessary because the high-tension neutral is grounded through a comparatively high resistance. This system has not yet gone into operation, but service tests are now being conducted, and will be reported some time in the near future.

Potential Ground Relay System

Another company reports a ground relay system which was devised to protect underground three-conductor lead cables from excessive potential strains upon the conductor insulation of the other phases when a ground develops on one phase. The cables are operated at 15,000 volts and each line is isolated from other parts of the system. Since the system is ungrounded practically no ground current flows when a ground occurs but the potential between the other conductors and sheath is raised from star to line voltage.

A schematic diagram of the installation is shown in Fig. 17. No special equipment is used, all apparatus being standard. The relay is of the over-current induction type and has a minimum operating current range of 0.5 to 1.5 amperes.

Referring to Fig. 17, when a ground occurs on *A*, for example, the potential transformer on that phase becomes short circuited, since the primary side of the potential transformers are connected in star and the neutral grounded. This in turn causes a current of low value to circulate through the potential transformer secondaries which are connected in delta through the over-current relay. Thus the relay will operate for a ground on any phase and clear the defective line.

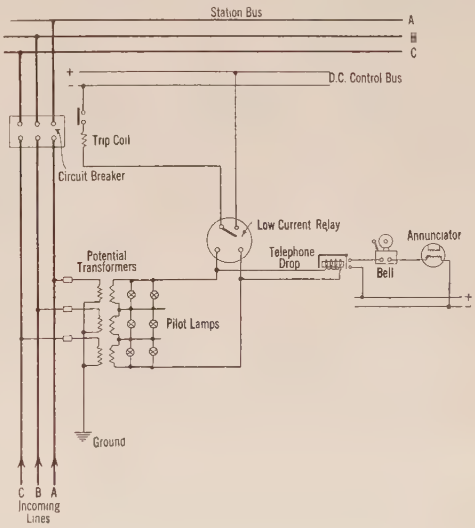

Fig. 17—Schematic Diagram of Potential Ground Relay System

This installation has been in operation since 1917, though no operating data are given for the period prior to 1919. During 1919 and 1920 there were 18 cases of correct operation and 2 cases of incorrect operation.

While the operation of the scheme has proved satisfactory it has been abandoned in favor of a scheme which will discriminate between lines and thus permit paralleling.

The installation has a threefold advantage in that it is simple in detail, is very quick to remove the trouble and functions without requiring any appreciable current to be flowing in the fault.

Its one great disadvantage is that, in case of a ground all the apparatus which it protects is disconnected. It, therefore, prevents the paralleling of feeders, as in an interconnected network or on parallel feeders all lines are likely to be opened on account of static unbalance.

Ground Selector Relay Scheme[3]

In order to overcome troubles due to grounds on a 12,000-volt ungrounded distribution system, one company reports the installation of a ground selector-scheme. The distribution system in question consists of approximately 80 miles of underground and the same amount of overhead distribution all fed from the same bus bar. Because of the extent of the system, grounds were quite frequent and cross short circuits sometimes developed before the ground could be located and cleared. This usually meant an interruption to a more or less extensive portion of the system. Some means of detecting and clearing the ground immediately upon its development was, therefore, very desirable and since the system was delta-connected this meant either the installation of grounding transformers

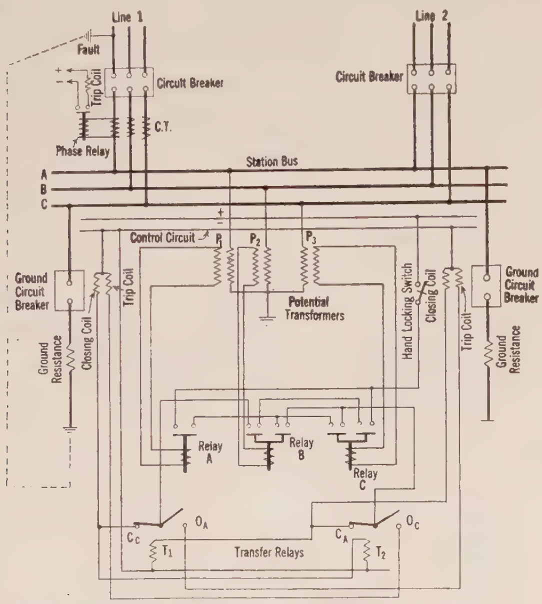

Fig. 18—Schematic Diagram of Ground Selector Relay System

or the development of some means of accomplishing the same results. After a thorough study of the situation it was decided to adopt the ground selector scheme shown in Fig. 18.

The principle of this ground selector is that any ground occurring on the system will immediately be developed into a short circuit by automatically grounding another phase at the base station and artificially completing a short circuit path. Short circuit current will then flow out into the fault, operating the phase relays and clearing the defective feeder in the same manner as if it was short-circuited. The artificial ground is made at the base station bus through an oil circuit breaker which is automatically opened as soon as the defective feeder is cleared, thus restoring the system to the normal condition. The circuit breaker is connected to ground through a very low resistance water rheostat which does not appreciably affect the magnitude of the fault current under the most limited current conditions, but has the advantage of sustaining the bus bar voltage in case of grounds near the base station, thus helping to keep the synchronous load in step.

Referring to Fig. 18, the essential features of the scheme are as follows:

The primaries of the three potential transformers are connected in star and the neutral point grounded. The secondaries of these transformers are each connected to an over-voltage relay, the action of any two of which will close the proper ground circuit breaker. So-called transfer relays are provided to insure the automatic opening of the circuit breaker as soon as the grounded feeder has been cleared.

Normally the three phases of the system will be balanced to ground, the potential on the transformers being the same and equal to 58 per cent of the voltage between phases. A ground on one phase will tend to lower the voltage on the corresponding transformer and the voltage on the other two phases will tend to rise to line voltage of 1.73 per cent of the normal voltage to ground. The over-voltage on the two sound phases operates the corresponding over-voltage relays and closes the ground circuit breaker.

As a specific example, assume a ground on Phase *A* of Line 1. This results in a high voltage on phases *B* and *C*, operating their corresponding relays and closing the ground circuit breaker on phase *C*. There is then a complete short circuit between phases *A* and *C* and the phase relays clear the faulty line. This leaves the grounding circuit breaker closed, resulting in a ground on phase *C*, and except for the transfer relay the other ground circuit breaker would close, due to the high voltage on phases *A* and *B*, and cause a bus short circuit. The transfer relay, however, locks the closing circuit of the second ground circuit breaker immediately upon the closing of the first one and at the same time prepares for the tripping of the one which has been closed. When the ground circuit breaker on phase *C* closes it energizes the coil of the transfer relay *T*-2, throwing the lever over into the other contact position. In this position of the lever, high voltage on phases *A* and *B* will trip the ground circuit breaker on phase *C* and reestablish normal conditions instead of wrongly closing phase *A* to ground through the other circuit breaker. In a like manner a defective feeder which may become grounded on phase *B* or *C*, will be cleared and normal conditions reestablished.

Other features which are not shown in the diagram but which are added to make the device practical are as follows:

A differential potential relay, responding only to unbalanced potential to ground, to prevent the over-voltage relays from operating on balanced over-voltage.

3. "Relay Protective Features of The Toronto Power Company's Transmission and Distribution System" by P. Ackerman. The Engineering Institute of Canada. April 1921.

Such action would not, in itself, be harmful, since the transfer relays would prevent the closing of the ground circuit breakers, but it would necessitate resetting the device, as the transfer relays are not automatically reset. It has been found advantageous to limit the device to one operation since automatic resetting might cause trouble if a ground should develop into a short circuit and clear the feeder before the ground circuit breaker is completely closed. The transfer relays are, therefore, arranged for hand resetting.

The ground circuit breakers are equipped with over-current relays set high enough to permit the feeder phase relays to operate before the ground circuit breaker opens. They are also provided with complete electric control which permits the operator to operate them manually if occasion arises. In addition, a hand locking switch is provided so that the automatic features can be removed without interfering with the hand control of the grounding circuit breaker.

This ground selector scheme was put into service in 1918 and its operation has been very satisfactory. During a period covering something over two years, operating records show that it effectively cleared a total of 86 grounds. Of these 86 cases of trouble, 40 were classed as permanent and were due to such causes as cable troubles, bad insulators, bad current transformers, operators' mistakes and testing faulty feeders. The remaining 46 were classed as transient troubles and were due to lightning and unknown causes probably customers' grounds or outside interference.

During this same period there were 41 momentary, self-clearing grounds, due to unknown causes, starting the ground selector but clearing before the ground circuit breaker closed.

The advantage of this ground selector scheme seems to be in the cost as compared to other schemes. The two alternative schemes for accomplishing the same result are as follows:

1. The installation of low reactance grounding transformers of large capacity so that sufficient current to operate the phase relays would be obtained, even on very remote grounds.

2. The installation of smaller capacity grounding transformers of higher reactance and the addition of special ground relays of low setting, which would take care of limited ground current.

The first was undesirable, in the case of the reporting company, on account of the inherent high cost of the high-capacity transformers and the second was equally undesirable because of the expensive relay and current transformer equipment required. Additional current transformers would have been necessary because all those available were fully loaded and the addition of new ones would have introduced complications on account of space limitations. The idea of grounding transformers was, therefore, abandoned in favor of the ground selector scheme.

The chief disadvantage is the loss of the advantage of a permanently grounded system. There is also the possible disadvantage of having no ground protection in case a ground should occur before the device is reset after an operation.

V. The Under-Voltage and Over-Current Combination. When a short circuit occurs on any part of a system the potential will be a minimum at the point of fault, increasing as the source is approached. This, therefore, provides another means of discrimination, which, in combination with over-current devices, may, under favorable circumstances such as long overhead lines, greatly increase the certainty of selectivity.

In the report of the Protective Devices Committee, submitted June 24, 1919, entitled "Transmission Line Relay Protection," there was described a method of automatically sectionalizing transmission lines, which made use of under-voltage and over-current relays. One of the companies installed this system about twelve years ago, and it has been estimated that the operation of the system, as far as the relays are concerned, has been about 85 per cent of perfect. However, this installation was made before reliable directional relays had been produced, and consequently, it does not contain any directional element, as a result, the circuit breakers on the incoming line, as well as on the defective outgoing line at each substation, were frequently tripped open so that on many cases of line trouble the substations at both ends of the defective line were lost. However, this was considered quite an improvement over previous conditions because it restricted the trouble to one section of the system, which is an important one and supplies an important industrial community. This scheme is now being superseded by conventional over-current and directional relays, but the Committee considers it of importance because it is a pioneer application of a protective relay principle which will, without doubt, soon be given another trial using more highly developed apparatus of greater refinement.

The Calculation of Short-Circuit Currents

A fault on a system produces an abnormal condition, which has no relation to normal loads and overloads, and in order to obtain selective action from over-current and directional relays, it is necessary to set them for the currents flowing under this condition. Feeder over loads can be taken care of by attention on the part of the operators.

This necessitates the calculation of short-circuit current values as a basis for relay settings. These calculations have been covered by numerous writers, so that this article will only give a description of a generally used method with references for those who desire further to investigate the subject.

Practically all short-circuit current calculations are made with reactance alone, resistance and capacity being neglected. In general, neglecting resistance and capacity does not produce an appreciable error except in certain types of systems. This reduces the calculations to an application of Ohm's and Kirchoff's

laws, using reactance in place of resistance. One method is to express the reactance of all generators, transformers, lines and other apparatus in ohms from one phase to neutral, and by adding up the reactance from the point of short circuit, to and including the generators, and dividing the sum into the voltage to neutral, the instantaneous value of the short-circuit current is found. This is the principle of the usual methods of calculations, but in systems having two or more different voltages it is necessary to express all the reactances in terms of one voltage and as the reactance of most apparatus is expressed in terms of percentage which is independent of voltage, and as line reactance in ohms can be easily converted into a percentage basis, the percentage method is generally preferred.

This method is described in an article by H. R. Wilson on page 475 of the *G. E. Review* for June 1916, in an article by W. W. Lewis, page 140, *G. E. Review* of February 1919, and in the article on "Rating and Selec-

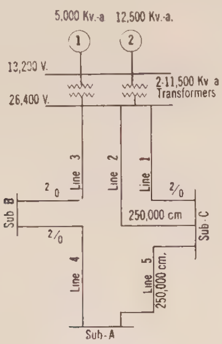

Fig. 19—Layout Assumed to Illustrate Calculation of Short-Circuit Current

tion of Oil Circuit Breakers" by Messrs. Hewlett, Mahoney and Burnham on page 123, Transactions of A. I. E. E. 1918.

A brief description of this method is as follows:

All reactance of generators, lines, transformers, reactance coils and other apparatus is expressed as per cent reactance at a common kv-a. base, arbitrarily selected. The various reactances are converted up or down as the case may be, to this base. The combined reactance from the generator neutrals to the point of short circuit is determined and it is assumed that the entire voltage of the generators is used between these two points. Then

1. Instantaneous kv-a.

$$= \frac{\text{kv-a. base}}{\text{reactance to point of fault}}$$

Example. With the layout given in Fig. 19 the calculations are as follows:

Line (1)—35,300 ft.
Spacing 24 × 24 × 34 S = 27 in.
Reactance per 1000 ft. = 0.1191 ohms
Total ohms reactance = 4.2
Per cent reactance on 10,000 kv-a. base = 6.0

In the same manner:

	Length	Spacing inches	Ohms reactance	Per cent reactance on 10,000 kv-a. base
Line (2)...	34,000 ft.	24 × 40 × 64	4.12	5.9
(3)...	56,000 ft.	24 × 24 × 34	6.70	9.6
(4)...	19,900 ft.	24 × 24 × 34	2.37	3.4
(5)...	33,400 ft.	24 × 40 × 64	4.04	5.8

REACTANCE OF APPARATUS

Apparatus	Kv-a. rating	Per cent Reactance	Per cent reactance on 10,000 kv-a. base
Generator No. 1......	5000	5	10.0
" " 2......	12500	12	9.6
Transformer " 1......	11500	5.75	5.0
" " 2......	11500	5.75	5.0

2. Reactance of the two generators in parallel $= 1/10 + 1/9.6 = 1/X$ $X = 4.9$ per cent
3. Reactance of the two transformers
$1/5 + 1/5 = 1/X$ $X = 2.5$ per cent
4. Reactance of Lines 1 and 2 in parallel
$1/6 + 1/5.9 = 1/X$ $X = 2.98$ per cent
5. Reactance of Line 3 + Line 4
$9.6 + 3.4 = 13.0$ per cent
6. Reactance of (4) + Line 5
$2.98 + 5.8 = 8.78$ per cent
7. Reactance of (5) in parallel with (6)

$$\frac{1}{13.0} + \frac{1}{8.78} = 1/X \qquad X = 5.3 \text{ per cent}$$

8. Reactance from Generators to Bus A
$(2) + (3) + (7) = 4.9 + 2.5 + 5.3$
$= 12.7$ per cent
9. Instantaneous Short-circuit kv-a.

$$\text{From (1)} = \frac{10000 \times 100}{12.7} = 78800$$

The instantaneous value decreases to the sustained short circuit value at a rate depending on the amount of reactance, generator characteristics, power factor of load on the generator at the time of the fault and other factors. Curves plotted from oscillograms taken on standard generators showing the current decrease for different values of reactance, are given in the paper by Messrs. Hewlett, Mahoney and Burnham, "Rating and Selection of Oil Circuit Breakers," on page 122 of the 1918 Transactions of the A. I. E. E.

If the short circuit value given above is to be used with a relay, intended to operate under these conditions in 1.2 seconds, the usual method is to set the relay for the current value at the end of the interval. To use the decrement curves, it is necessary to use the reactance of the point of short circuit based on the total generating capacity. Converting the instantaneous short circuit kv-a. (9) to a per cent reactance based on the total generating capacity of the system.

Per cent reactance at 17500 kv-a.

$$= \frac{17500}{78800} \times 100 = 22.2 \text{ per cent.}$$

Referring to the decrement curves for 22.2 per cent reactance and 1.2 seconds the number of times full load current is found to be 2.52. Therefore, short circuit current at 1.2 seconds

$$= \frac{2.52 \times \text{gen. kv-a.} \times 1000}{1.73 \times \text{line voltage}}$$

$$= \frac{2.25 \times 17{,}500 \times 1000}{1.73 \times 26{,}400} = 964 \text{ amperes}$$

When the system has lines other than in parallel-tandem arrangement or is fed by more than one generating station, the solution becomes more difficult and if the network is complicated, the process becomes too tedious to be practical. Simple network solutions

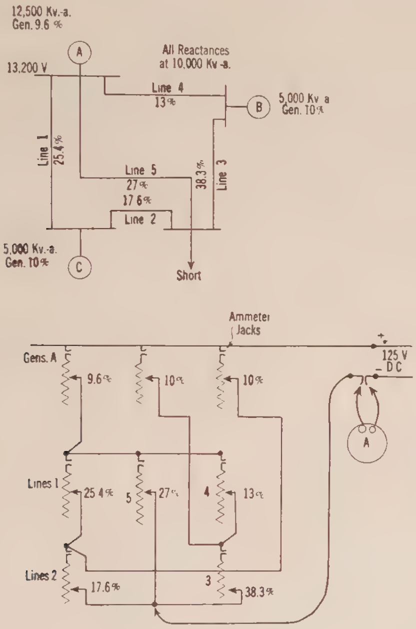

FIG. 20—TYPICAL LAYOUT AND SET-UP FOR CALCULATING TABLE

are given in the two references above and methods of solving networks are described in articles by R. D. Evans and Charles Fortescue on pages 345 and 350 respectively in the *Electric Journal* of August 1919.

Calculating Table. The difficulty in the complete mathematical method lies in determining the system reactance to the point of short circuit, and the distribution of current among the many lines and generators. The calculating table covers this step in the process.

The table consists of a number of adjustable rheostats that are given an arbitrary rating. The original table and many built since, have the rheostats rated at 125 volts and a normal current of 0.2 ampere. The rheostats are calibrated and marked with some form of scale so that with 125 volts applied across the resistance the 0.2 ampere point is 100 per cent reactance, the 0.4 ampere point 50 per cent, etc., resistances of the value of 500 to 1200 ohms being used giving a reactance range from 0 to 80 per cent and 0 to 180 per cent approximately. Leads enable the resistances to be interconnected as the generators and various elements of a system. One end of the generator rheostat is connected to one side of the 125 volt source and the point of short circuit is connected to the other side. An ammeter jack in each rheostat circuit allows the current to be read with an ammeter.

The set-up of a more complicated problem is given in Fig. 20.

The ammeter inserted in the negative lead reads 1.7 amperes and, since 0.2 amperes is equal to 100 per cent reactance on the table basis, 1.7/2 = 8.5 times the table base in kv-a. The readings for all elements are as follows:

		Generators			Lines				
	Total	A	B	C	1	2	3	4	5
Actual readings	1.7	0.56	0.46	0.694	0.068	0.76	0.396	0.058	0.532
No. of times normal	8.5	2.8	2.3	3.47	0.34	3.8	1.98	0.29	2.66

It is interesting to note that the flow over line 4, is from *B* towards *A*. This is directly indicated by the ammeter in the table set-up.

Instantaneous kv-a. = 8.5 × 10,000 = 85,000
Instantaneous amperes at 13,200 volts = 3720
Generating capacity = 22,500
Per cent reactance on generating capacity base

$$= \frac{22{,}500}{85000} \times 100 = 26.5 \text{ per cent.}$$

The distribution of the current in any part of the network may be determined as follows:

Current over line 2

$$= 3720 \times 3.8/8.5 = 1660 \text{ amperes}$$

The remaining part of the calculations and the use of the decrement curves are exactly the same as in the mathematical solution.

The original calculating table was described in the *G. E. review* page 901—August 1916. Other tables have been described in the *G. E. Review* of February 1919, page 140—August 1920, page 669 and *Electric Journal* August 1919, page 345. The first tables were actually in the form of tables, the later ones are in the form of a panel or cabinet.

In the latest boards, the plugging is done with telephone jacks and cord circuits, which makes a somewhat more compact arrangement and the leads of each rheostat are looped through telephone keys within reach of the operator so that the current in any part of the table may be read by the pressing of a key, without "plugging" an ammeter jack in circuit, as was necessary in the first designs.

One of the latest tables built is shown in Figs. 21 and 22.

This table was built by the testing department of the Commonwealth Edison Company, and consists of an oak cabinet, in the lower portion of which are mounted 60 adjustable rheostats, five on each of twelve panels; 60 pairs of telephone switchboard cords, connected

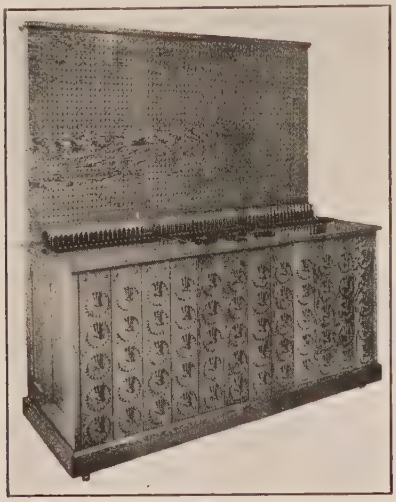

FIG. 21—VIEW OF A LATE DESIGN OF CALCULATING TABLE

through switch keys to the rheostats; a flush type ammeter and voltmeter; a reversing switch and shunt selector switch for the ammeter and the main switch for the table. On the upper panel are 30 horizontal rows of jacks, each row forming a bus, but except for the lower two rows not permanently connected to the lower part of the table. The first and second rows are the positive and negative buses of the table and are

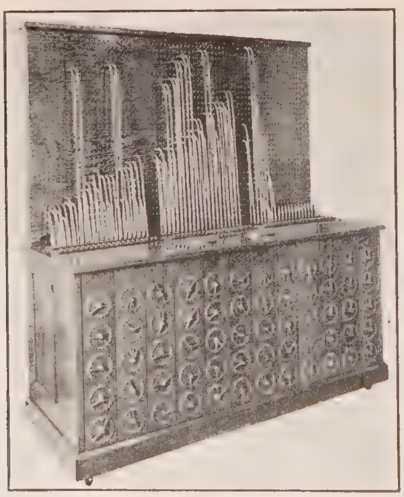

FIG. 22—CALCULATING TABLE SET UP FOR SYSTEM SHOWN IN FIG. 25

connected to terminal blocks at each end and to the voltmeter and the main switch.

The rheostats each consist of four enameled resistance units, two of 500 ohms each with 100-ohm taps, and two of 50 ohms each with 10-ohm taps. Each rheostat is therefore adjustable from 0 to 1100 ohms in steps of 10 ohms. The mounting of the resistance units is shown in Fig. 23.

The switch keys in the circuit of each pair of cords and rheostat furnish means for readily connecting these circuits to the ammeter bus. A wiring diagram is shown in Fig. 24. Only one circuit is shown in this diagram, as all the others are similar.

The arrangement of horizontal busses on the upper panel makes unnecessary any crossing of cords. This

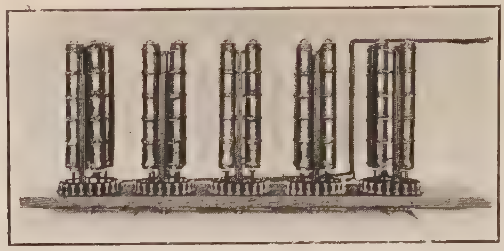

FIG. 23—RESISTANCE UNIT OF CALCULATING TABLE SHOWN IN FIG. 21

is a feature possessed by no other table, and is possible regardless of the arrangement of the lines or station busses represented on the table. More jacks are required by this design, but the setting up and working of the table are greatly simplified, the chances of making errors greatly reduced, and the set-up is always

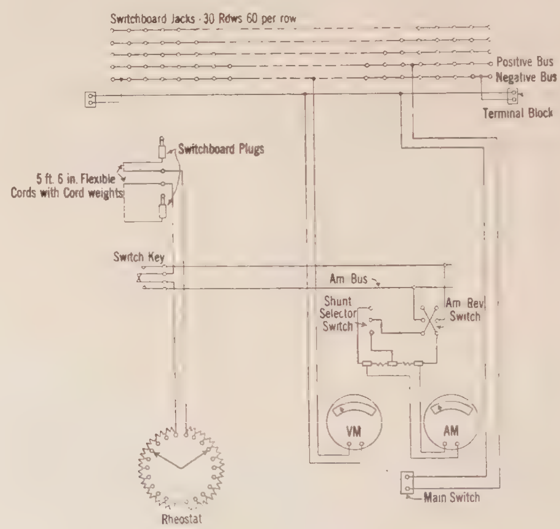

FIG. 24—DIAGRAM OF CONNECTIONS—CALCULATING TABLE

readily traced or checked. Fig. 22 shows the table set up to represent the network in Fig. 25.

Since the photographs were taken, there have been added card holders in each row of jacks, mounted in the two vertical blank spaces on the upper panel, in which slips may be inserted, giving the names of the station or substation for the set-up; also brass dial plates for each rheostat, giving the number of the rheostat and the number of each step.

A few companies have made tables with fixed resist-

ances, each resistance representing a specific line, generator, etc. in the system. Where the elements in a system are not numerous and in cases where changes are not frequent, this cuts down the cost of the table considerably. In one form of a calculating "board" using fixed resistances, the resistance to the point of short circuit is measured by a self-contained Wheatstone bridge. The current distribution may be calculated by obtaining the potential drops at the various points in the network.

The tables and boards have been found valuable for calculating short-circuit currents for the selection of oil circuit breakers as the method of calculation is the same as described here. The table also forms an easy way to determine the size of reactance coils necessary in designing station bus layouts, as the resistances repre-

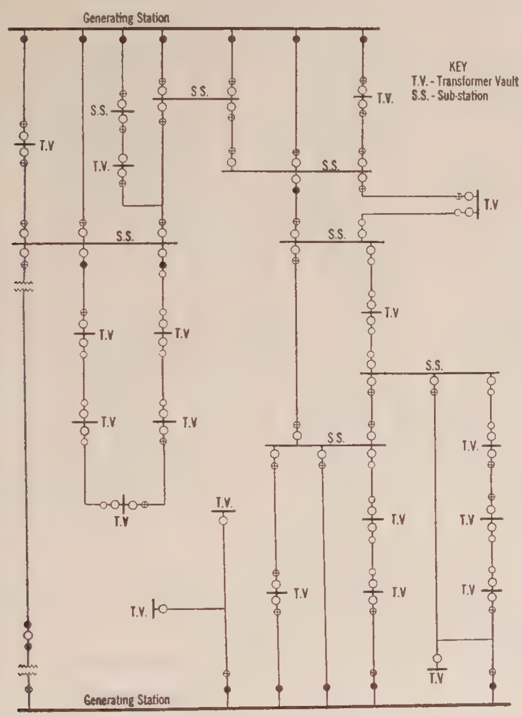

FIG. 25—DIAGRAM OF SYSTEM SET-UP ON TABLE IN FIG. 22

senting the reactance coils can be varied until the short-circuit value is reduced to the amount that the oil circuit breakers can safely interrupt. Various schemes can be quickly set up and the relative effectiveness of the reactors determined.

Inasmuch as the use of the table necessitates neglecting either the resistance or reactance of the various system elements, voltage measurements are not accurate in general.

The error in neglecting the resistance depends on the type of system. Where there are numerous reactance coils or transformers between the generators and the various substation busses, the error is not appreciable. In the article by H. R. Wilson on page 478 of the *G. E. Review* for June 1916, previously referred to as open wire system with 13,200-volt and 2300-volt generators, 88,000 volt lines and step-up and step-down transformers, the error between the resistance—reactance calculations and the reactance calculations, is 2 per cent. In a system where there are no transformers or reactance coils this error becomes greater. The magnitude of this error will depend on the system and a study of this condition for a system consisting of cables or for a system without reactance coils or transformers, should be made to see if the table may be used with a fair degree of accuracy. For a complicated network, however, the table is practically the only solution, but it is well to determine approximately the amount of the error.

The error between the mathematical solution (neglecting resistance) and the similar table solution varies with the number of elements in the set-up and the values of reactance used to set the rheostats. Where the reactance values were such that the rheostats were set well up on the scale, and when there were a number of elements in the set-up, the table figures have checked the mathematical calculations to 1 per cent or less. If possible the table kv-a. base should be changed to obtain reactance figures that will bring the rheostat pointers well up on the scale, values of 50 per cent or more being preferable to 5 to 20 per cent.

In regard to errors it should be remembered that the table figures do not need to be of a high degree of accuracy, as there is considerable error in the reactance values, especially the open wire figures, and the variations in operating conditions are generally so great that the errors in the table and those due to neglecting resistances, are not appreciable.

In obtaining reactance values on generators from the manufacturers, it is important that the reactance obtained be the transient or inherent value and that it be applicable to the decrement curves. It is quite common to furnish the synchronous or sustained value of reactance unless otherwise specified.

A close study of operating conditions is required to determine the generating capacity to be used in the calculations, as there is generally a variation of capacity during each 24 hours, during the week and during the year.

In addition to taking into consideration the variation of capacity in stations, it is also necessary to study the effect of stations that may be entirely shut down during part of a period, only being operated during the peak, or in case of emergency.

A close study of the line operation is also necessary, as the relay scheme and operating scheme must go hand in hand, for neither can obtain the best results independently. One changed method of operation may destroy the effectiveness a well-designed relay scheme, whereas some other change in operation would result in more effective protection. Relays that require time and current settings for selectivity cannot always be set to meet every possible operating condition. Therefore settings that fit the normal conditions and

as many of the emergency variable conditions as possible should be used. Likewise operation rules cannot always be made to fit the relay schemes, but if the operators are kept advised as to the field that the scheme covers, they will, where possible, pick out emergency connections and make other operating changes to fit in this field. Also if informed of these conditions, when it is necessary to go outside of the limit of the relay scheme the operators will know what to expect and will be able more quickly to locate any trouble or faults. In general, for selective relay protection it is best to operate the system with all lines in service and to eliminate, insofar as possible, special conditions such as split busses.

Whether it is necessary to take into account the synchronous load on the system depends on its relative capacity with regard to the total generating capacity. Motor-generators and synchronous converters that have an interconnected d-c. system tending to keep up their speed have a much greater effect than synchronous condensers that have only their inertia to attempt to maintain their speed.

Relay Application

Relays are applied to transmission systems in order that customers may be given continuous service and that the revenue lost by the power company through interruptions may be a minimum. Protection supplied, to apparatus is of secondary importance and is a field which is not covered by this paper, although properly designed transmission relay schemes correctly applied are a distinct advantage in this respect, as the strains on apparatus are reduced by the time limitation imposed by the line relays.

Each relay system and each piece of apparatus entering into the make-up of the system has definite characteristics and limitations. In a like manner each transmission system, and in fact each line making up that system, has definite characteristics which distinguish it from other lines or systems. Satisfactory applications cannot be made without complete knowledge of the characteristics of the protective relays and associated apparatus and of the transmission system and lines to which the applications are to be made. Adequate relay schemes have been condemned through the failure of the application engineer to recognize and weigh all of the factors involved. In some cases difficulty is experienced in isolating or evaluating a factor until after an installation is in service, or an error is made in application, but careful analysis of operating records, supplemented when necessary by tests, will reveal the weakness in the scheme or the value of the factor which was omitted from consideration with the result that the installation may then be corrected or a more suitable scheme installed. At least one case of this type was reported by an operating company and subsequent results show that the diagnosis, made after a number of faulty operations, was correct.

There is a tendency at times, to complicate installations by the use of auxiliary devices to make relays perform operations which are the functions of the operators. The attempt to endow protective relays with judgment in addition to the usual function of discrimination leads to disastrous results through the failure of the auxiliaries to function properly. Maintenance charges are high on such installations, reliability is sacrificed to intricacy, and the service rendered is not commensurate with the cost.

Many relay schemes are, of a necessity, complicated but the trend should be toward simplicity and, other things being equal, the simplest installation selected.

One other item which is frequently overlooked is the phasing out of installations before cutting into service. This work can be done most intelligently by the engineer in charge of relay applications, or at least under his supervision. One company reports that it is its practise to have three independent checks on phasing made before cutting an installation into service. These checks are made under load conditions, first, by the engineer in charge of construction or his representative; second, by the testing department; and third, by the engineer in charge of protection, or his representative. In this way the work of the various departments is properly coordinated.

General Practise in Relay Settings and Tests

Emphasis should be placed upon the necessity of having one person in authority to determine what current and time settings shall be given to all important relays on the system. The testing and adjusting of the relays, after the settings have been determined, need not be so centralized but it seems to be the usual practise and, as outlined in a preceding paragraph, would appear desirable.

The man who determines the relay settings must be in close touch with the operating department so as to be acquainted with all of the operating conditions, weak spots in the system, such as inadequate circuit breakers and lines, and important loads which must be given preference when laying out the protective scheme. Usually the relay man is a member of the engineering department or, less frequently, of the operating department. Another method is to handle protection of the system through a committee consisting of one or more members from each of the interested departments. The personnel of such a committee will depend to a great extent upon the organization of the company.

The use of inaccurate current transformers such as the low-ratio through or bushing type, may necessitate special consideration when determining the current settings of relays, but after the relays are installed no difficulty need be encountered in testing the assembled equipment if the method mentioned in the previous paper is followed. In this connection, it may be well to point out that even with transformers of these types, the phase angle error will seldom prevent the use of directional relays.

Potential transformers do not, as a rule, enter the problem of setting relays except in cases where the phase relation between the high-tension line and the relay potential bus is shifted 30 degrees by the introduction of star-delta transformers which may make it necessary to adopt some expedient to secure the proper phase relation and voltage value for directional relays.

Practically all circuit breakers now being manufactured will open the circuit in less than 0.25 second so successive relays may be given a time difference of 0.5 second and thus allow a wide margin of safety. Smaller time intervals are being used in a few cases but this is not usually advisable unless each circuit breaker has been individually calibrated and is given frequent inspection. The increasing attention which is being given to the problem of automatic sectionalizing is emphasizing the importance of careful adjustment and inspection of the circuit breakers.

Many companies test their important relays with a cycle counter at the time of installation and thereafter at intervals of six months or a year depending upon the importance of the service and the location of the relay. This test is made regardless of the care and accuracy of the factory calibration because of the very nature of the installation which places considerable responsibility on a single piece of apparatus which will receive little attention after it is once installed and therefore should be thoroughly tested and verified before it is placed in service. Furthermore, a test of the relay with current makes certain that it is in good mechanical condition and if the current is applied near the current transformers the condition of the wiring is also verified.

Notes on Foreign Practise

A larger proportion of the transmission systems in European countries consist of closely spaced conductors than is common practise in America, as the density of population, relatively short distances and lower voltages make this form of transmission more desirable. As a result, differential current schemes of protection have received more attention and a number of principles utilized which are entirely different from those found in American practise.

In England, in particular, more attention seems to have been given to differential schemes than any other form of relay protective equipment, and the development of over-current and directional relays has lagged accordingly. Originally, pilot-wire protection was preferred, then split-conductor, and at present the preference seems to be returning to pilot wire. Methods of eliminating capacity effects in pilot wires and the relatively cheaper first cost as compared with the split conductor, would account for the reversion. The English schemes lead in diversity of principles employed for selecting the faulty line but in methods of application and the development of devices, American practise seems to be superior.

The influence of developments in the art in each country is beginning to be felt in the other country and it is to be hoped that some of the basic principles established in England will be adopted in America, as the English engineers have already adopted some of the American schemes. In this connection it is interesting to find that one company in the Far East, operating under the supervision of an English engineer, installed during the recent war, the American adaptation of the split-conductor scheme for closely spaced conductors. The special oil circuit breaker consisting of six poles (two in each phase) to clear trouble on end faults as used in English practise, was not obtainable, so, after visiting the American installations, the modified scheme was adopted consisting of standard three pole circuit breakers and end reactors to assist in clearing end faults.

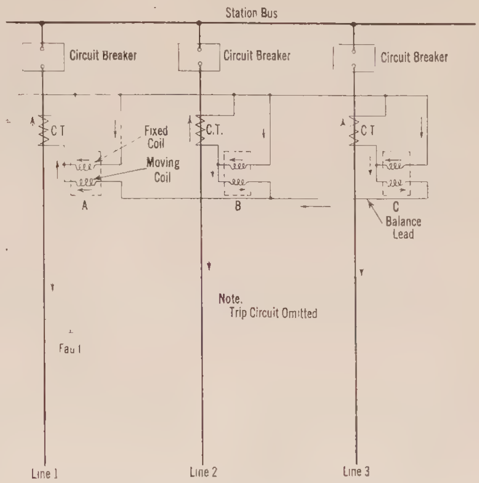

Fig. 26—A Typical Differential Scheme as Used in English Practise

Many of the English schemes require the use of special conductors and their use is not economically justified except in special cases, because of the large capital expenditure required to obtain only slightly better protection than is obtainable by other and cheaper means. There are, however, a number of other schemes which do not use special conductors and which are desirable because of the stability obtainable with very low settings. A typical example of this form of protection applicable only to outgoing lines is shown in the single line diagram, Fig. 26.[4]

The relays employed in this scheme are the directional current type having a fixed coil and a movable coil. Under normal operating conditions the current from each transformer circulates through the fixed coil of its relay. The moving coil connected to the balance lead is not excited. If the faulty line 1, carries the greatest current as would be the case in an installation

4. Automatic Protective Devices for Alternating Current System. A. E. McColl. Jour. Inst. of Elec. Eng., July 1920 page 525.

on three parallel lines, the balance of the secondary circuit is disturbed, the residual current flowing through the balance lead and moving coils in such directions as to operate the relay with its fixed coil connected to the faulty line and restrain the other relays. The greater discrimination obtained by introducing a definite restraint upon relays connected to healthy lines during abnormal conditions is a principle which should be given consideration in this country for both transmission line and apparatus protection.

In other countries also, recognition is being given to the advantages of differential protection. In Spain there is a transmission system supplying a territory of some 16,000 sq. km. (6177.6 sq. mi.) with a load of 152,700 kw. in 1921 consisting of a network of 110-kv. and 25-kv. lines. On the 110-kv. system there are nine installations of differentially-connected directional relays and two installations of differentially-connected over-current relays. In the 25-kv. system there are two installations of differentially-connected over-current relays. This company is also installing ground relays on the 110-kv. lines to obviate difficulties which it has experienced with the failure of phase relays to operate quickly on ground faults during light load periods and at such times as the differential protection is inoperative due to a line being out of service. These ground relays will have very low settings and the company states that the relays are expected to clear grounded lines before the fault develops into a short circuit between phases.

A relay[5] in which the time element is a function of line voltage has been developed and placed on the market, an installation being considered on one of the high-voltage, single-phase systems in Switzerland. These relays have a potential coil restraining element, the amount of restraint being directly proportional to the line distance between the fault and the relay, thus, those relays nearest the fault will select the proper line as they are subject to the minimum restraint.

Operating Records

There is one suggestion which may well be emphasized and which followed, will undoubtedly increase the value of the work of the committee besides increasing its efficiency and making the work less burdensome. In analyzing the replies from the various reporting companies it was found that some were much more comprehensive than others. From further analysis it became evident that the most difficult ones were from companies who apparently did not have any *good method* of keeping a complete record of interruptions and relay operations. Companies who kept such records were able to answer, definitely, questions to which others could give only vague replies. This lack of definite information was less noticeable in the descriptions of equipment and schemes than in operating results. This would seem to indicate that each company thoroughly investigates the apparatus and schemes before installation and keeps a record of the installation, but that, in a great many cases, adequate operating records are not kept. The engineer in charge of the relay system may know, in a general way, the results that he is getting from his protective equipment but unless a record, giving each detail of operation of the apparatus involved, is kept it will be difficult to determine the effectiveness and next to impossible to make a report showing whether satisfactory results are being obtained from any scheme.

It has been the experience of some of the largest companies in the country that such a record is invaluable in determining the worth of various protective schemes and in choosing the method of protecting new lines. Since beginning to record and compare operating results it has been found possible to determine without difficulty the cause for a great many incorrect operations and to increase the efficiency of protection.

It is the operating data which determine the value

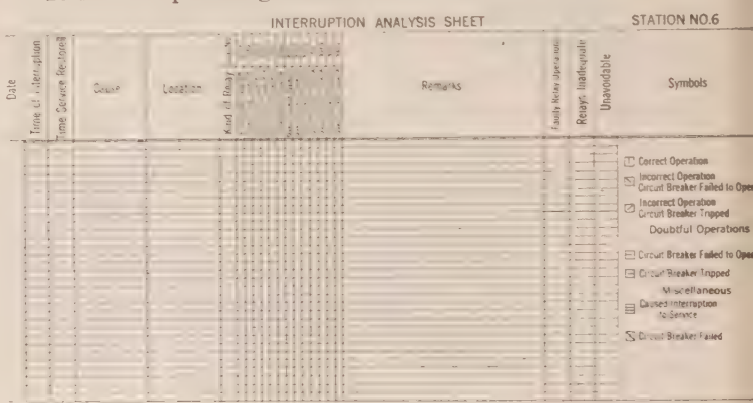

Fig. 27—Suggested Form for Recording Interruptions and Relay Operations

of any protective scheme and that such data may be more easily collected and analyzed, the Protective Devices Committee is prompted to suggest a form of Interruption Analysis Sheet, as shown in Fig. 27. A form similar to this has been used with very satisfactory results by several operating companies.

An examination of this form will show that provision is made for recording every detail of the Interruption and relay operation. Unusual features which cannot conveniently be classified may be entered under the heading of "Remarks". A sheet is made up for each station and a cross index with other stations which may be involved can be obtained by referring to them under "Remarks". Each incoming and outgoing feeder is identified with the type of relay by which it is protected, and space is provided for recording and conclusions drawn from the analysis; that is, whether an interruption may have been caused from faulty relay operation, inadequate relay protection or other cause, or whether it was unavoidable.

The form shown is, of course, subject to modifications

5. *E. T. Z.* No. 50, 1919 and January 16, 1920.

to meet various conditions but it is felt that an Interruption Analysis Sheet, embodying these essential features will permit the keeping of all the details of operating records in a compact and easily comparable form.

It is, therefore, recommended that operating engineers give this suggestion serious consideration, as it is of greatest importance that the operating companies know exactly what results are being obtained in order that such schemes as do not give adequate protection may be replaced by more effective schemes, thus stimulating progress and weeding out such schemes and devices as have not proven satisfactory.

* * * * * * * *

It is to be hoped that the foregoing descriptions of schemes and practises in transmission line relay protection will result in a clearer understanding among engineers of the present state of the art. It is the purpose of the series of papers on Protective Relays to keep operating engineers informed as to what is available for meeting each and every operating requirement and to keep designing engineers in close touch with the problems met in the operating field. In order to fulfill this purpose the Protective Devices Committee must have the full cooperation of both the operating and the designing engineers. The cooperation which has been given and the interest which has been shown in the work have been very gratifying.

Discussion at Pacific Coast Convention

DISCUSSION ON "RECENT CONCLUSIONS PERTAINING TO ELECTRICAL PRECIPITATION"* (SCHMIDT). **"ELECTRICAL ENGINEERING FEATURES OF THE ELECTRICAL PRECIPITATION PROCESS"†** (HORNE), **AND "ELECTRICAL PRECIPITATION OF SOLIDS FROM SMELTER GASES"‡** (RATHBUN),

Vancouver, B. C., August 11, 1922

C. E. Skinner: It is rather curious that this process, developed primarily to abate a nuisance should become so valuable economically. I have been familiar with some attempts in the Pittsburgh district to abate the smoke nuisance by the Mellen Institute of Industrial Research. They made a smoke survey of Pittsburgh, and a study of this survey shows how desirable it is to abate this nuisance in the Pittsburgh district. However, the values recovered are not such as to justify the cost from the commercial standpoint, and consequently very little has been done.

E. P. Dillon: Mr. Schmidt's paper is very opportune, as it presents clearly an explanation of phenomena which have for many years been an obstacle to precipitation engineers in their efforts successfully to handle certain kinds and conditions of gases that do not lend themselves readily to effective clean-up in Cottrell precipitation treaters.

It is shown that the suspended fume or dust carried in practically any gas may readily be precipitated by proper conditioning of the gas, and while in the case of certain gases there is an apparent anomaly in the relationship between precipitation efficiency and current flow, when such gases are properly conditioned the expected normal relation obtains between precipitation efficiency and current flow.

In substantiation of the theory that a non-conductive deposit on the receiving electrode retards if not entirely stops precipitation, numerous observations have been made, and in a particular instance where the material to be precipitated was ground button dust, it was found that with perfectly clean plates the precipitation was for a short period practically perfect, but after a deposit had collected on the plate precipitation ceased, and in this same problem it was possible, by properly conditioning the gas with the idea of making the deposit conducting, to maintain continuous precipitation.

Mr. Schmidt's analysis of the economics of "treater" design is extremely important, since it is the engineer's function to so design and proportion plants as to show to the user the maximum return on the investment, and knowing the conditions, the designer, by Mr. Schmidt's method, may readily so proportion his plant as to accomplish thus result. With the data obtained from wide research and extensive experience now available to engineers, it is possible to design "treaters" for practically any problems of cleaning gas that will in practical operation obtain a predetermined percentage of recovery or clean-up. It is obvious, therefore, that the proportioning of the "treater" for the percentage of recovery to be obtained will depend to a very large extent on the economics of the problem to be solved, and it is indeed fortunate that engineers are now equipped with information permitting them to take cognizance of the economic elements in designing a "treater" for a given problem.

The necessity of properly conditioning gases has been brought home to precipitation engineers in the problem of precipitating zinc oxide perhaps more forcibly than in any other operation. The recovery of this material, whether pure or impure, by means of precipitation from gases not properly conditioned is extremely difficult. With the increasing knowledge and experience of conditioning gases, it is now considered entirely feasible successfully and economically to treat gases carrying zinc oxide, removing therefrom the fume at any pre-determined and desired efficiency. Gases of this character have been successfully handled in numerous commercial installations, as well as various test problems, with gas volumes from 5000 to 20,000 cu. ft. per min. at temperatures of treatment up to 700 deg. fahr. the fume content of these gases so treated being as high as four to five grains per cu. ft. of gas at standard conditions. In general, the conditioning of these gases has been accomplished by the addition of steam or water, and it is an interesting fact that when so conditioned that effective precipitation resulted, it was found that the precipitate was in a dry form, as required for commercial conditions.

In most of the earlier electrical precipitation installations the treaters were of the open type discharging into the atmosphere, or if closed were so designed merely for the purpose of conducting the gases to stacks. Recent developments, however, have brought about designs of gas tight treaters where the gas is used after being cleaned in the treater, and such gas tight "treaters" have been used in some instances for the cleaning of explosive gases. Numerous installations of the gas tight treaters are now in commercial operation, giving very satisfactory results and evidencing material progress in applying electrical precipitation to an ever widening field of gas cleaning.

Referring to Mr. Rathbun's paper. In the earlier stages of the practical application of the electrical precipitation processes they were considered applicable only to the recovery of sulphuric acid

*A. I. E. E. JOURNAL, 1922, Vol. XLI, July, p. 547.

†A. I. E. E. JOURNAL, 1922, Vol. XLI, July, p. 552.

‡A. I. E. E. JOURNAL, 1922, Vol. XLI, September, p. 676.

mist, and, as Mr. Rathbun states, for some time later they were thought of as a means only for abating a nuisance. The variety of the applications of the processes to gas cleaning problems has extended to such a point that now practically any fume or dust recovery problem is susceptible of solution by these processes. In fact, the metallurgist and chemist is now free to develop processes disregarding fume losses, even going so far as to create fume losses in process operations, since the Cottrell processes may be relied upon for efficient economical recovery of such losses.

The description of the wire type "treater" is extremely interesting, particularly in view of the fact that it is based on actual experience, and it is undoubtedly a valuable contribution to the subject of precipitation. Draft losses are an ever present problem to the precipitation engineer, and constant efforts are being directed to minimize such losses in modern designs. Modern installations are so designed that the draft losses will not exceed 0.25 in., and in a wide variety of installations it is found that the draft loss is much less than this, ranging from 0.15 in. to 0.10 in.

The presence of sulphuric acid in some form in the gas is certainly a great aid to precipitation, and the idea suggested by Mr. Rathbun of adding sulphuric acid by various methods to the gases, with the attendant favorable results, indicates a material advance in the art of precipitation. In many plants, however, sulphuric acid is not available for such use, and it has been found in a wide variety of operations that eminently satisfactory conditioning of the gases can be obtained by the proper introduction of water or steam, and this result has been obtained in numerous instances with gases at high temperatures of treatment with a resulting dry precipitate, thereby indicating that in some problems at least the use of steam or water for conditioning is not confined to cold gases only.

As Mr. Rathbun says, the electrical equipment for precipitation has been very well worked out and developed, and we agree entirely with the statement that "the electrical side of the process is of less importance than the treater and gas conditioning. In selecting the number of electrical sets for a given installation, there is room for careful thought on the part of the engineer to so proportion the electrical equipment as to insure a reasonable flexibility and at the same time avoid unduly burdening the installation with an increased investment, keeping in mind the necessity, however, of having available a sufficient number of sets to obtain the desired precipitation efficiency. The general trend of treater design seems to indicate a tendency at this time toward the lower voltages. The selection by Mr. Rathbun of 15-kw. sets as standard checks with general practise, although in some smaller installations sets of smaller capacity are used, but it is generally conceded by precipitation engineers that large capacities such as 50 kv-a. or over are not desirable and are rarely if ever used.

The operating voltage of the treater can be predetermined with fair accuracy, but the most effective voltage to be used will vary with changes in gas condition, velocity, etc. and the electrical equipment is so arranged that adjustment of voltage on the treater can readily be made by the operator to obtain best precipitation under existing conditions.

O. H. Eschholz: To the engineer electrostatic precipitation will always serve as an excellent illustration of the successful utilization of advanced scientific knowledge for the development of an important industrial process. While in other electrical systems the presence of corona too frequently is indicative of energy waste or impending failure, in this process it functions as an essential operating agent. Fume, vapor or suspended solids, ionized in the corona surrounding the discharge wire or chain are propelled through an electrostatic field of decreasing potential gradient to finally impinge upon the surface of an adequate receiving electrode. Because of the importance of the corona phenomenon, interest is frequently centered on the character of the treater voltage wave.

On an oscillograph record of treater voltage and current, the peak voltage as measured by sphere gap was 57,000 and the effective voltage, as determined from the oscillogram, was 97 per cent of the peak. The effective mechanical rectifier ground current on this quite large treater was approximately 1 ampere. Numerous oscillograms taken of treater voltage under varying conditions of gas flow and treater capacity gave in most cases effective voltage values exceeding 90 per cent of the peak. This quite flat character of the voltage wave is doubtless responsible for Mr. Horne's observation that the substitution of a high-voltage direct-current generator (Girven) for the mechanical rectifier does not give a substantial increase in precipitation efficiency.

It is of interest to note that the velocity of the charged particles, or heavy ions, is quite low owing to their relatively large mass. This had been estimated[1] for one set of conditions to be of the order of 0.8 in. per sec. Upon disconnecting the supply circuit as a result of this low ion velocity the heater discharge is found comparatively slow. The discharge rate is somewhat greater than would be estimated from the above value of velocity due to the discharge of the treater energy through the oscillograph circuit as well as to the displacement of the ionized gas by the incoming uncharged furnace gases. As a result of the low "ionic drift" considerable energy is stored between electrodes. This energy assists in maintaining treater voltage or serves to quickly reestablish such voltage in the event of a short circuit caused by a break-down between electrodes.

Owing to the slow movement of the charged particles, only those in the immediate path of the arc were discharged, thus permitting the immediate reestablishment of treater voltage when the arc had been ruptured at the contacts of the mechanical rectifier. It is important to note that because of this low ionic drift and the breaker-like action of the mechanical rectifier, the precipitation time lost due to treater shorts is negligible so that it is practicable to operate treaters very close to their critical break-down voltage.

Some consideration should be given to the fact that treater circuits may serve as a source of high-frequency radiations and hence cause "wireless interference." Observations on a small plant have shown that energy stored in the treater proper is radiated from the transmission line, functioning as an antenna, at the natural frequency of the system, as a result of the intermittent corona or arcing occurring in the treater. In the case studied sharp resonance was obtained with the wave meter located at the top of the treater at 150 and 300-meter wave lengths. The sound in the receivers was very similar to the frying noise characteristic of the treater corona. Various expedients may be adopted to reduce the energy of the high-frequency oscillations such as a high resistance in the treater end of the transmission line—a ground wire screen under the antenna—a condenser across treater line and ground at rectifier end or possibly substitution of steel for the usual copper line wire.

J. C. Hale: There are a few points in Mr. Horne's paper which may lead to questioning by those not thoroughly familiar with the subject and it seems desirable to amplify somewhat on certain portions of the paper.

The relative advantages of the synchronous motor and motor-generator set depend largely upon the characteristics of the power supply circuit to which they are to be connected. If the regulation of this circuit is extremely poor it may, as the author has said, be advisable to install a motor-generator set to secure better operation. Sufficiently close voltage regulations to permit entirely satisfactory operation of the present type of synchronous induction motor has been found in practically all the installations which have been made east of the Rocky Mountains. The disadvantage mentioned,—that a synchronous motor requires careful attention on the part of the operator in starting up to secure proper polarity, is in practise unimportant, as the

[1]Electrostatic Precipitation, H. H. Eschholz, *Proc.*, A. I. M. & M. Eng., Vol. 60, p. 243.

operator can immediately reverse the polarity if necessary by means of the double pole double throw switch shown in the author's wiring diagram, Fig. 1. In most cases the proper polarity can be determined as shown by Mr. Horne in Fig. 5 of the paper. If the wrong polarity is obtained the precipitator will arc over before the voltage can be raised to the proper operating value.

The disadvantage that the synchronous motor may slip a pole due to momentary low voltage is, of course, important. Actual tests on the latest design of motors now being furnished by the manufacturers show that they will not drop out of step (or slip a pole) unless the voltage is reduced by somewhat more than 20 per cent. If regulation as poor as this is encountered a motor-generator set certainly should be installed. Such poor voltage regulation is, however, rarely encountered.

With reference to the disadvantages of the motor-generator set, there is a further point which applies especially to small power units, (5, 10 or even 15 kv-a.). It has been shown by oscillographs that unless special attention is given to the generator design the voltage wave obtained from a 5-kv-a. or even a 10 or 15-kv-a. gnerator will be very badly distorted by the oscillations set up by the transformer rectifier circuit. These oscillations are of course too small to react upon the wave shape of a large generator such as would be found on a power circuit. It cannot be definitely said just what is the effect of those wave distortions upon the efficiency obtained in the precipitator. It is obvious however that, if there are very high peak voltages they will prevent, by causing an arc over, the maintaining of a sufficiently high average voltage to secure most efficient precipitation.

With reference to Fig. 6, the reader should be carefully warned not to draw an erroneous conclusion from the curve given. The author's conclusion is unquestionably correct, but it should be borne in mind that although the curve given is typical in shape for all precipitation circuits it will differ in each installation in its location with respect to the coordinates. It might be inferred from the curve given that the maximum obtainable efficiency of precipitation is about 90 per cent. Any desirable location with respect to the abscissa can be obtained by a change in the operation or design of the precipitator unit; in other words, any desired efficiency can be obtained by a suitable precipitator design and there are installations in commercial operation which have shown, by actual test, a continued efficiency of 99½ per cent.

Emphasis should be laid on the reliability of the electrical equipment now available for use in connection with the electrical precipitation process. Eight or ten years ago the objection to the mechanical rectifier because of the high-frequency oscillation set up in the high-tension circuits was very serious and a great many transformer failures occurred. Since that time, by careful study of the problem, the manufacturers of electrical equipment have been able to supply suitably designed and constructed transformers and to protect them by means of external resistance or reactance so that the transformer failures very seldom occur at the present time. All of the other apparatus used in obtaining and controlling high-tension unidirectional currents have been from time to time the subject of study and improvement, and, as a result, thoroughly reliable equipment is now obtainable.

Svend Barfoed: I would like to ask Mr. Schmidt one question: In the treatment of smelter fumes I understand that you can remove SO_3 fumes from the gases, as it is in the nature of a solid. I have not read the paper but I wonder if SO_2, which is a true gas, can be so treated that it also could be removed from the gas so that it will not constitute a nuisance.

W. A. Schmidt: I know of no case where SO_3 has been precipitated as such. SO_3 is very difficult to isolate since it combines very readily with any water vapor present. There is usually sufficient moisture present in the gases to immediately form sulphuric acid which is H_2SO_4. If sufficient sulphuric acid is so formed to exceed the saturation point of the gases at the temperature existing then this excess will form a mist of liquid particles of sulphuric acid and be precipitated as acid or combined with other substances present.

The question of the precipitation of SO_2 has often been raised. SO_2 is a gas and this process does not effect any separation of gases. The suggestion has been made to oxidize SO_2 to SO_3 and convert to sulphuric acid, but that has to date proven impractical.

R. J. C. Wood: It may be of interest to tell about the electrical precipitation that we have been getting on the Big Creek lines. We have a very large precipitator there, 200 miles long and 100 feet wide. We noticed when going over the line some couple of years ago that the aluminum cable was perfectly bright up in the higher altitudes, up near the power houses at the Big Creek end. It looked exactly the same as it did when installed, absolutely new, bright and shining. As you got down into the lower altitudes that brilliancy began to fade, and at two or three thousand feet or so it was of a light brown color. By the time we were down in the San Joaquin Valley it was quite dark brown. By the time we got to Eagle Rock, down near Los Angeles, it was dead black. However, crossing the Tejon Mountains, it lost its color again as it ascended the altitudes—apparently some kind of mountain sickness.

I took a piece of that cable from the Eagle Rock end—and examined it, and I thought at first that this was just discoloration of soot and I could brush it off with my hand. I rubbed it with my hand and I got just a little stain on my hand but the deposit did not come off, and I rubbed harder, and I rubbed until I began to get sore, but still did not remove this coating. All I did was to put a very nice black polish on this coating. The wire looked just like black enamel wire. Finally I got the coating off with either dilute acid or dilute caustic soda. The black powder that came off in the solution I examined under the microscope and found that it was made up of grains of translucent material, I suppose little bits of the country, little bits of rock and dust, and interspersed between those grains were very small black points or spots, but the rather astonishing thing was the transparency of the preparation under the microscope. We expected to see large masses of dark black substance, whereas it looked like a piece of ground glass broken up with just a very few black spots on it.

I am assuming that the voltage on the line causes precipitation of particles flying in the air, that up in the higher altitudes there was not sufficient of the black carbonaceous binder to make the particles stick together, that in the lower altitudes where there was a good deal of oil smoke and so on, the binder cemented the clearer particles together, making a hard coating on the wire. Practically you might say that this coat is a microscopic macadam.

I would like to ask Mr. Schmidt also whether by the use of the treater he could cut part of that very tall stack off. The stack as made—and it is an enormous one, 560 feet high, as I understand—was originally made of that height in order to carry the gases and dust to a sufficient height so that they would not fall on the immediately surrounding country, but be carried off to somebody else. Now, if you put in a precipitator and collect these fumes possibly you might be able to save somewhat in the height of this stack.

W. A. Schmidt: In answer to Mr. Wood's question I would say that in certain cases the stack could undoubtedly be decreased in height, and in fact at some places the stack has been replaced entirely by fans; but in the particular case to which Mr. Wood refers, which is the Anaconda Smelter, that is not true. As a matter of fact, the stack is on the top of a hill, quite a good height above the smelter, and the stack is proportioned so as to give the desired draft behind the furnaces to overcome the resistance in the flue system.

I might say one word in connection with the thought that came to my mind when Mr. Wood spoke of the collection of dust on the high-tension transmission line. As I showed in my in-

ormal discussion, the effect of a deposit upon a surface when that deposit is composed of porous or discontinuous dielectric is such as to convert the surface into an ionizing medium. It would be very interesting to obtain some measurements on the high-tension transmission lines on the effect of such deposits on the corona losses. It is quite possible that there might be a distinct effect there.

There is one other question which I would like to touch on in connection with Mr. Rathbun's paper. He speaks of the difference in effectiveness of the wire treater. He unfortunately overlooked pointing out that with the type of construction to which he refers it is possible to put a very large amount of discharge electrode in a very small space. The work which Anderson and Horne conducted, and which is discussed in my paper, shows that after all every treater in its effectiveness follows an exponential equation, and we have no evidence at hand indicating that an arrangement such as Mr. Rathbun refers to in his discussion of the wire treater has any greater effectiveness per unit length of discharge electrode. In fact there is some evidence indicating that the effectiveness per unit length is less. But he does obtain a greater length of discharge electrode with the same cubical contents of the treater, and that, of course, has a distinct bearing upon the cost.

C. N. Beebe: As was pointed out, in Mr. Rathbun's paper, the wire screened treater and also the wire treater were capable of being installed in the present existing flue chamber. It is a fact that modern smelters do not hesitate at all to make an expenditure of millions of dollars on a complete new treater plant; with the wire screen or wire type of treater, which is capable of being installed in the short length of existing flue chamber, the same amount of gases can be treated with the treater, costing three per cent. of a million dollars, or $30,000 approximately. This will give you some idea of the saving to the smelting industry of the research work which Mr. Rathbun has accomplished.

W. A. Schmidt: In connection with that statement I wish to call attention to the fact that in all those cases where the installations have cost sums approximating a million dollars new flues were constructed, and in a measure the entire flue system was scrapped and rebuilt. In the case that Mr. Beebe is referring to, the electrical equipment was on hand, and the cost of installation simply covered the insertion of electrodes into the existing flue.

R. B. Rathbun: The period of six months, which has elapsed since the paper on smelter gases was written, has done much at the various plants at which the author has contact to substantiate the views expressed in the paper on the subjects to "treater design" and "conditioning of the gases."

Discussion of the paper seemed to have centered around the development of the new wire treater described briefly under the head of "Treater Design", together with the other types of treaters.

In view of the remarkable record for construction and operating costs being made at present by this treater in the precipitation field it should require no defense.

Mr. Schmidt remarked in his discussion that it was perhaps unfortunate that the fact was not pointed out that with this type of construction it is possible to put a very large amount of discharge electrode in a small space. The advantage of this is obvious. He does, though, go on to infer that the lessened cost is due to its greater length of discharge with the same cubical contents of treater as in the other types. This would make it appear that its advantages lie almost wholly in its ability to dissipate a large amount of electric power in a small space, whereas it is clearly shown in the paper that economy of power over other types was one of its advantages. It was clearly demonstrated that this, and its high efficiency per unit of cost, was due largely to the fact that it provided a large number of electric fields in series in the same chamber and staggered with reference to each other so that every gas molecule must of necessity pass close to a discharge electrode where the potential gradient is steep enough for its ionization. The fact is again pointed out that in other treaters, such as the pipe, a large portion of the gas passes out parallel to and through the weak field adjacent to the passive electrode which is the wall of the pipe.

In the introduction of the paper it was stated that the subject would be covered from the standpoint of the engineer whose watchword must always be "return on the investment." From this viewpoint it seems immaterial whether or not this treater is covered by the exponential equation developed by Horne and Anderson. It is no doubt a very interesting academic point, however. Nor does it seem important if its superiority measured by the standard of the dollar is conceded whether or not the effectiveness of the discharge per unit of length is less than in other types, as intimated by Mr. Schmidt. This statement, by the way, seems misleading when not qualified, It must be remembered that in the wire treater the gas flow is in the direction of the discharge instead of right angles to it, as in other types, making such a comparison difficult.

It is usual to think in terms of the ionized length, or the distance through which a given gas molecule is in the influence of the electrical field. In the wire treater this length is rather less than in other types for a given gas velocity and cleaning of the gas, having as it usually does only 20 electrified spaces of 6 in. each in series, whereas in pipe treaters the gas usually passes through from 12 to 15 ft. of ionized length.

Mr. Dillon has in his discussion noted one of its very important advantages—that of extremely low draft loss, not to exceed 0.25 in. It might be added that for pipe treaters, performing under like conditions, it is often as much as ½ inch. This conservation of draft is partly due to the fact that the wire treater, equipped with insulating lime seals where live members enter, has practically no infiltration of outside air, but it is mainly due to the fact that the gases are not deflected from their straight course from the furnace to the chimney and suffer practically no interference due to friction of the treater interposed in their direct route.

In regard to Mr. Schmidt's qualifying statement to that made by Mr. Beebe regarding costs. It is true, as the former states, that in the instance cited a large part of the saving was due to the use of flue chambers already in use. In a large sense it was the adaptability of such chambers to this system which led to its development. However, instances have been found where the existing flue does not lend itself readily, and in such cases it is found that a short portion may be rebuilt and the straight line principle maintained without seriously affecting the cost.

Regarding "conditioning the gases." Mr. Dillon, in commenting on present methods as described in my paper, felt that in these considerable progress had been made in the art of precipitation. That is true—but it must be realized that the methods of humidifying or acidifying gases difficult to treat are but makeshifts since the former is injurious to flue and treater system at temperatures where water will condense, and the latter is often prohibitive due to the cost of the acid.

An account of some preliminary microscpoic work, together with micro-photographs showing the physical properties of fume and flue dust, was submitted in the paper. It was hoped that this would lead to discussion, or pave the way to constructive thought toward the final solution of this important problem.

DISCUSSION ON "TESTS AND INVESTIGATIONS ON EXTRA HIGH-TENSION INSULATORS"* (Farr and Philpott).

Vancouver, B. C., August 8, 1922

W. A. Hillebrand: I will confine my discussion principally to the paper by Messrs. Farr and Philpott. The energy and care with which they prosecuted this research is highly commendable, and the results are extremely interesting. On the other hand it is characteristic of a great deal of such work that an attempt is

*A. I. E. E. Journal, 1922. Vol. XLI. October, p. 711.

made to draw general conclusions from incomplete data. For example, the insulators on which they made their tests were evidently of very poor material.

Another factor which they have overlooked, and which is very frequently overlooked in such a series of tests is the time-puncture characteristic of the material. That must be known fairly well before one can obtain definite results. Of any lot of insulators a small percentage will puncture at dry flashover voltage. This percentage depends upon the quality of the porcelain, and is proportional at least to the first power of the time the voltage is applied. This always enters as an unknown factor in any series of tests involving periodic applications of voltage.

The insulators reported upon are of designs now largely obsolete, which has a bearing on the question of time constants and the superior ability of an oscillator to puncture under test, which has been known for a number of years. A long, deep shell similar to the type used in the earlier pin-type insulators manufactured ten years ago, may have a 60-cycle flashover of 50,000 volts. Under an impact or oscillation that flashover will run up to seventy-five, eighty thousand—perhaps double. The design is such that when a steep wave front is impressed upon it the porcelain withstands a very much higher flashover than do designs that are such as are used today, with consequently greater liability to puncture.

One very interesting thing which they bring out is that whole insulators were used in their porosity test, and that they succeeded in a very large number of cases in driving the fuchsine right through the glaze. That is not altogether surprising in view of the fact that the glaze is continuous with the porcelain body and of composition similar to the binding material in the porcelain itself. Except for the fact that it is on the outside and more exposed to the heat of the kiln, it should have a density similar to that of the body of the porcelain.

One fault to be avoided in such work is to draw conclusions from old material and attempt to apply them to ware as it is manufactured today. As a result, the authors are apparently in a mood to impose a rigorous specification upon the manufacturer, a procedure which often has been disastrous in the past. That is, an insulator can be designed to meet almost any requirement desired, but there is a very great danger, and it has very often happened, that such insulators will be very short-lived. There are a number of disastrous examples on record.

With regard to the possible cause of failure of insulators due to lap checks, sand streaks and so forth. One very interesting example of that was brought to my attention last year by an engineer who had dissolved the caps of a large number of insulators in acid. He showed me one shell that was absolutely down by the megger, which probably had a sandstreak or a lint streak in the head. Over many square inches of area he had with true Oriental patience, searched until he located a spot perhaps one-sixteenth of an inch in diameter, or less, where alone the porcelain was porous and down.

H. V. Carpenter: I am convinced that the manufacturers are now giving us some porcelain which is different from that which we have had in the past, and a great deal of data which we have had presented to us in past papers refer to the older type. Now the manufacturers will probably tell us that the old troubles are all taken care of, but is it not likely that we are doing the thing which has been done so many times in other things, substituting something which is really a new product now in the better porcelain? It is better undoubtedly but perhaps it has some new peculiarities which we still have to learn; so I am very much interested in the suggestions made in regard to the tests for the mechanical difficulties which are likely to arise, and to determine whether the failures which are now coming may not be almost entirely mechanical.

H. H. Schoolfield: I recently had occasion to make a test on one of our 66,000-volt transmission lines with the Johnston buzz-stick method. The insulators on this line had not been tested by megger or any other method since they were installed in 1912. I made the test this last spring and found only about three per cent of the insulators showed bad by that method. I consider this a very good record for a line built with insulators purchased in 1912.

There is no question but that we are getting a better grade of insulators now than we did then, and I expected to find a great many more failures than I did. The line was somewhat under-insulated too, compared to the way we insulate lines nowadays. It is a 66 kv. line with three cap and pin type units in suspension and four at strain points. One thing I did find though, that bears out some of the discussion this morning—that the larger percentage of failures was at the point of support, at the pole or cross-arm end of the string.

I also took a good many of the insulators that showed failure under the buzz-stick method, and checked them up with the megger after they had been taken down, and I am satisfied in my own mind that the megger does not give an accurate test; does not show accurately the bad insulators in the line. Some of the insulators that would show bad with the buzz-stick might show a high rating under the megger, but put on an oscillator test they would fail. Give them a high-potential test they would fail, although the megger did not show them bad.

There are a great many factors entering into testing with the megger. Atmospheric conditions, have to be watched very carefully, so I am very much inclined to favor a method similar to the buzz-stick for picking out bad insulators. I think a good many insulators might show bad under a megger test that should not be removed. A few years ago we made a practise of taking out an insulator from a string that would megger anything below 4000 megohms; between 3000 and 4000 megohms. Under that practise I think we took out a great many insulators that should not have been condemned. If we had left them in they would have stood up.

The line that I speak of, however, was in a very dry section of country, where we don't have very much rain. It wasn't in Portland, but was in the north central part of Oregon, around The Dalles. That may have had something to do with the low percentage of bad insulators we found.

R. J. C. Wood: Mr. Schoolfield's remarks have led me to think that it might be interesting to give a little outline of an instrument we have developed—under the direction of the engineers of the Southern California Company—to do the same work as the buzz-stick without some of the dangers that are inherent in its use. It seems to me that Mr. Schoolfield had his nerve with him when he used a buzz-stick on a line that had not been tested for so many years; with only three units on 66,000 volts. If he had happened to strike two bad units in the same string it would have resulted in an accident. In order to eliminate this danger, which is not so great on a 66 or 60,000-volt line where there are four units, but is very great on a 15,000-volt line where there are perhaps only two units, we made a little device, which is practically an electroscope. It is constructed of a piece of one-inch square bakelite tube with two vanes inside. Another electrode is wrapped around the central portion of that tube, the tube being a foot or so long, and some more square bakelite tube is slipped over the outside so that there is nothing hot exposed, the connection of the two vanes is brought out to one of the prongs on the end of the device and the outer piece of metal connected to the other prong, and the whole thing is mounted upon an insulating stick. Putting the prongs across an insulator if there is voltage across it the loops inside vibrate, and sighting through the end of the open one-inch square tube it is easily seen whether the vanes vibrate or not, and there is no danger incurred as there is no metallic circuit through the testing device.

H. L. Melvin: As far as the operating engineer is concerned, what they do want is a product which is uniformly good. Just what tests are necessary to weed out poor material we are not prepared to specify. Both design and tests are primarily manu-

facturing problems. The manufacturer must cooperate with the operating engineer to find out what the particular problems are. Operating companies are at fault in that until just recently, with the exception of a few of the larger companies, they have not kept records of failures or really studied the problem.

If we are now satisfied with the standard types of insulators it is the manufacturer's problem, to introduce as many logical improvements in the manufacturing and assembling of parts as they are able to devise to insure life to the insulator under operating, mechanical and electrical stresses. They must also devise tests which will insure the purchaser against the purchase of defective material.

However, I am convinced that further study of operating stresses both mechanical and electrical, must be made and tests devised to duplicate them. These tests may lead to a modification of the present general design as operating conditions become more severe.

Allen E. Ransom: During the war, I was Chief Electrical Officer, Major Commanding 137th Engineers at Base Section No. 1 St. Nazaire, and had occasion to use a good many insulators throughout that base. We were connected up with the French systems through the large Central Stations at St. Nazaire, Nantes, Angers, Saumur and other points. The Haviland works at Lyons were making insulators for the use of the American forces and put out a very fine grade of white porcelain insulator for 5000 and 20,000 volts. These with intermediate voltages were used on our temporary lines all through Base No. 1 and also at Brest and Bordeaux and the intermediate sections up towards the Front. We built something like 200 miles of primary and secondary lines and never had any insulator failures.

The machinery we had to use was mostly French which we obtained from the Westinghouse Works at Le Havre and the General Electric works at Lyons. We had no trouble with their motors and transformers at all. A great deal of the American machinery sent over was 2300 volts, 60 cycle. Standard French distribution primary voltage is 5000 volts, 3 phase, 50 cycle and 230 and 460 volts on secondary power circuits so American 60 cycle motors were all right.

The transmission lines throughout the Atlantic Coast section of France were almost all 20,000 volts and using power and light from steam turbine generating stations in the principal cities there being no hydroelectric stations in this district. Our experience with the French insulators was very satisfactory.

DISCUSSION ON "FAILURE OF DISK INSULATORS ON HIGH-TENSION TRANSMISSION"* (Panton).

Vancouver, B. C., August 9, 1922

R. J. C. Wood: There is a very interesting thing in Table 3. In the early years we find that the No. 1 disk is the one which is failing to the greater extent, in 1913, 1914, 1915, 1916; and then in 1917 No. 7, which is the one nearest the point of support, usurps first place and keeps approximately that position, so that on the whole in these latter years it is the one nearest the point of support which shows the greatest number of failures. Now we all know that in the years 1913, 1914, the kind of insulator we were getting was very different from the insulators we get today; and that raised the question in my mind as to whether those early failures may not have been due to one cause—perhaps soft, porous porcelain, which was to be had in plenty; and the failures of the later years, when it is to be presumed that most of that poor stuff had been weeded out, have been caused by prolonged mechanical vibration.

W. A. Hillebrand: Experience with insulators on this line has been extremely interesting. There are several points worthy of note. One is the extremely low rate of failure of insulators in the suspension position over a period of seven years. It is one of the very best that I know of, as you will see from Table 3, very much better than the records of many comparative insulators over the same period. The second is a comparatively high rate of failure of insulators in the dead-end position. so much so that I think after three years they were all removed in favor of another type.

Now, I think within a year after the construction of this line, it was subjected to a heavy sleet loading such that over one section there was about one conductor break per mile, with about twenty conductor breaks all told. This meant that the dead-end insulators were practically all over-stressed, which may have influenced their high rate of failure. This is particularly likely to be true, if as is my belief, many types of suspension insulators are operated under a false mechanical factor of safety, that is, the actual unit stresses are very often considerably higher than what is calculated.

In the matter of vibration there is one case at least on record of an insulator having been practically pulverized from this cause. In another case of a transposition tower, insulators, which were subjected to practically no weight whatsoever, were failing at such a rapid rate that it was necessary to add a very considerable weight simply to damp out the vibration stress.

The question has been raised as to the reason for the peculiar shape of the curve shown in Fig. 1, that is the higher rate of failure of the insulator next to the conductor than that of the one above. It is to be noted that this paper is probably a record of insulators removed from all causes, as a result of line testing and of actual failure in operation.

Porcelain is a heterogeneous, conglomerate material consisting of an aggregate and a binder. The mechanism of its failure is probably that of a slowly developing crack similar to the well known depreciation of tableware. As the bottom unit of a suspension insulator string has an operating potential considerably higher than that of any other unit it is conceivable that a deteriorating insulator would at last be weakened to the point where it would be punctured by the operating voltage. For an equal rate of depreciation this would occur more frequently in the case of the bottom units than with the others.

Porcelain is never completely annealed. Due to daily temperature changes it is subject to working stresses within the body of the material itself, independent of any which may be imposed by cemented hardware. These facts incline me to a belief in a gradual deterioration of the manner stated. Furthermore, so far as I am aware, there is nothing in all ceramic experience to indicate that a large percentage of insulators now being manufactured will not deteriorate at a slow rate.

E. E. F. Creighton: I want to take up that point that Mr. Wood asked, I think, and which bears directly on the subject, deterioration. In order to find out what was the matter I made two different kinds of tests; one I will mention at the present time.

Hundreds of insulators were punctured. After each one was punctured the process was to take some red dye and with the vacuum on the opposite side of the punctured hole send the dye through the hole, then set the insulator aside to dry. It took a day or so usually—if you want to have it done thoroughly. Then I take up the insulator and find what sort of puncture hole takes place.

We found from those tests that nearly all the punctures were due to folds or defects in the porcelain. As soon as you break it to pieces you will find that the dye has run in little flat streaks in there so that the porcelain actually opened up and there was a big flat place in there. If a porcelain punctures because of porosity you will find the puncture takes the shortest path through the porcelain, that is, if the porcelain is three-quarters of an inch thick it will go straight through the three-quarters of an inch. In general, however, the path of the discharge is very much longer than the thickness of the porcelain, showing that there was a definite defect.

The three ingredients, clay and feldspar and the flint in proportion, usually about five, three and two, are mixed with water

*A. I. E. E. Journal, 1922, Vol. XLI, Nov., p. 819.

in a large vat, and then it is necessary to get enough water out so as to get the clay in plastic form, that means going through a filter press, and the filter press takes out perhaps a little bit too much water. At any rate, these filter cases, about two inches thick, about two feet square are piled up one on top of the other and hammered down, and they are mixed as much as possible and hammered down in the pile and left for several days for the moisture to equalize, then they are put through a machine and thoroughly mixed up. Now during that process there are these little air pockets that may be in there, most of them to be sure eliminated or we would not have got good porcelain at all, but these little pockets do from time to time continue through all that process, and those are the little incidental conditions which make porcelain unreliable.

Now those of us who have worked with porcelain realize that a perfect piece of porcelain is an accident. It is a craft and it is only a question of how great those holes are.

Now, does porcelain deteriorate, is there any chance that we will ever get to a place where we can count on the porcelain for an indefinitely long time? In order to get some data on that subject I made up a large wheel that I have described elsewhere, called the Ferris wheel. It would not pass in here—it would turn in this room. On the outside of that wheel insulators were placed, standard insulators. At the bottom we used a special cooling means to get the temperature down to twenty degrees below zero, Fahrenheit. At the top we put in heating units and resisters so that we could raise the temperature any desired amount. In between we had a cooling space of air. With that apparatus we could change the temperature of the insulator over a range far greater than it would have in practise.

Now we put an insulator through that process, and assuming that twice around was equivalent to one year, we carried the insulators through dozens and dozens of years of life. The test was perhaps a little more severe than they would get in practise.

We have no very good way of determining whether there was deterioration there, but this much we can say that after they had passed through those many temperature changes, running it in and out continuously we could detect no deterioration of the porcelain. That gives hope that the porcelain does not deteriorate, in fact to the contrary, for the well-known methods of manufacture of porcelain it is my feeling that there is no deterioration of porcelain itself. The deterioration, as has well been pointed out by Mr. Wood, is mechanical.

Ivar Herlitz: In the years 1914 and 1915, a large number of suspension insulators were installed on the 70-kv. transmission lines operated by the Swedish Board of Waterfalls. The design of these insulators was preceded by considerable research work. An account of the principles brought out by this research work, and of the operating results with the insulators, was recently published in the Swedish technical literature (*Teknisk Tidskrift*, Jan. 1922). A brief summary of some aspects of this paper may be of interest in this connection.

The essential principles for the design of these insulators were as follows:

1. The porcelain was, as far as possible, relieved of tensile and shearing stresses; the possibilities for concentrations of the electrical field were reduced by avoiding all sharp corners.

2. Cap, pin, and porcelain were cemented together in such a way as to allow the metal to expand and contract freely in the axial direction under temperature variations; stresses on account of radial expansion of porcelain, cement, and metal were eliminated by means of elastic cushions between the various parts.

3. Certain experiments having indicated that electrical phenomena in the cement might have a detrimental effect, it was decided to short-circuit the cement by means of a conducting film on the porcelain, which film was connected to the cap and pin respectively.

More than 70,000 insulators of this design have been in operation for 7 years without showing any aging phenomena. Some 20 units have been exchanged, but only on account of damage from arcs.

Experience has indicated that the short-circuiting of the cement is of little importance, but the demand for this feature accidentally gave rise to an interesting experience. On the first insulators the conducting film was made of graphite, but on a later delivery, of which 8000 were put into operation, lead had been used. Of these insulators, 15 per cent failed in a few years. An investigation showed that this was entirely due to the fact that the lead became oxidized and thereby greatly expanded. This seems to furnish a strong argument for the importance of taking care of the stresses caused by expanding cement.

H. D. Panton: In reply to Mr. Wood I will say that we have never purchased any of the cap and pin disk insulators in question since 1911; replacements up to the present time having been made with disks removed from other lines when reinsulated with other disks. Disks so removed are tested with the G. E. oscillator, and those found good have been used for making replacements on the line under discussion in my paper. It is very probable that Mr. Wood's conjectures with regard to the cause of failure of No. 1 disks in the years 1913 to 1916 are correct; that such failures were due to defective porcelain. However, it must be borne in mind that the tests made in 1913-14-15 were not as thorough as those which have been made in subsequent years.

Referring to Mr. Hillebrand's remarks the average failure of suspension disks in ten years including 1922 has been only 1.5 per cent per year. With regard to the high rate of failure of insulators in dead-end assemblies, these were so high, that by the end of 1914, when the line had been in operation for a little over two years, it was necessary to decide on a replacement of all these insulators used in dead-end assemblies with insulators of another type.

The sleet storm referred to by Mr. Hillebrand occurred on April 1st-2nd, 1915, when this line had been in service for three years and we had already experienced so much trouble with these dead-end assemblies that we were preparing to replace them with Hewlett disks prior to the time when this sleet storm occurred. This storm caused the line to go down in over 40 places in a section forty-six miles long, practically all breaks being due to conductors breaking under the load of snow and ice; the snow and ice on the line was so heavy that a piece of No. 6 telephone wire measured in the storm area was found to be 9-in. in circumference, that is inclosed in an ice and snow sheath nearly three inches in diameter. Comparatively few insulators were found to be defective after this storm when a routine test of all insulators of this line was made. On suspension assemblies only 0.4 per cent of the disks were found defective. Figures are not available but I do not believe we found any large number of strain insulators which had failed due to the stresses put upon them by this storm.

With regard to Mr. Creighton's "ferris wheel test" I do not feel that two trips around his wheel produces stresses in the insulators equal to those experienced during a year of service on the transmission line. I consider the most severe stresses experienced by insulators in this section due to temperature changes, to be those produced when a cold shower falls on a hot summer day. The temperature of the porcelain in the sun is around 120 deg. Fahr. or higher and that of the rain in the neighborhood of 60 deg. Such an experience as this will happen to all of our insulators at least 25 or 30 times each summer. The top disk is most exposed to an experience of this kind and we have thought that this was possibly the cause why disks in this position failed with the greatest frequency. It is to be noted that the disks in discussion have no elastic cushion of any kind between the porcelain, the cement, and the metal. The cement being in direct contact with both the porcelain and the metal. Certain compressive stresses are obliged to be set up due to temperature changes; whether these stresses are of sufficient intensity to rupture the porcelain, I am not in a position to state.

DISCUSSION ON "AN OVERPOTENTIAL TEST FOR INSULATORS"* (LAPP).

Vancouver, B. C., August 9, 1922

C. E. Skinner: Porcelain is essentially in effect a conglomerate of spar, flint and kaolin. Each individual piece has its own personal history. A very large number of factors inevitably enter in, to affect it for good or ill in its making. Much can be done by the ceramist and by the porcelain factory to insure uniformity, but the day will never dawn when lots of porcelain insulators can be tested by sample as we test steel and many other materials. We must always test each piece to see that that piece does not have accidental defects and weaknesses that would unfit it for its intended service. What is required is a test that will search out such defects and weaknesses and which will leave the piece uninjured by the test itself. It is up to the porcelain manufacturer to so operate his plant that he secures the maximum of uniformity, and the test should eliminate all pieces which fall below an agreed standard. The agreed standard should be that which gives satisfactory service under the prescribed conditions. As no test can duplicate service conditions—in fact probably no series of tests can duplicate service conditions—the combined experience of manufacturing, testing and service will finally show what balance should be struck between severity of test and service. We can so test that we destroy every insulator, then we have none for service. The most careful manufacturer cannot hope to so fabricate that no test is required, so there must be an economic balance between test and service. We all welcome any test that will help to show us whether design and material are right, and any test that will eliminate insulators which would not give service.

Mr. Lapp's test is one which should aid designers and manufacturers in determining whether design and material are right, and possibly may be justified in certain cases for a routine test where conditions are unusually severe. I very much doubt, however, if this test will entirely eliminate insulators which would develop flaws or faults in service, and particularly those which may be due to mechanical stresses.

I think the test is one that we should all welcome and give a thorough trial. It will not be an easy test to carry out on large numbers of insulators.

C. L. Fortescue: Mr. Lapp seems to have made out a very good case for the method of testing insulators which he advocates. However, he falls into some errors in his anxiety to make a case for this type of over-potential test. In high-frequency tests for example, the applied frequency as he says, is damped trains of the order of 100,000 to 200,000 cycles a second, but the actual frequency of the test to which the insulator is subjected may be many more times this frequency for the reason that flashover of the insulator sets up another train of damped oscillations which are superimposed on the impressed train. The severity of the high-frequency test is due to the fact that for each half cycle of the 60-cycle current supplying the high-frequency set many more damped oscillations of the natural period of the insulator occur than in the case of the 60-cycle flashover test. However, there is, as Mr. Lapp remarks, a question if such a test may not cause damage by the heating due to the high frequency localized stresses, which are incidental to such tests, and therefore, it becomes necessary to limit such tests to a comparatively short period, as compared to the 60-cycle routine test.

In the 60-cycle routine test the actual 60-cycle applied voltage is not the time test voltage, but the flash-over of the insulators superimposes a highly damped train of oscillation at every half cycle which raises the potential to a value considerably above its normal 60-cycle flashover of the insulator. In order to obtain the best results with this test the impedance of the transformer should be at the proper relation to the capacity of the low and the applied frequency. When this condition is approximated this method appears to be a very reliable routine test for insulators.

*A. I. E. E. JOURNAL, 1922, Vol. XLI, July, p. 491.

The overpotential attainable is, as Mr. Lapp states, limited by the impulse ratio of the insulator, but so too is the impulsive stress to which the insulator is subject under operating conditions. Indeed, if we would make a true comparison we would find that, if anything, the potentials to which the insulator is subjected under routine test are several times more severe than any surge they are likely to get in service.

Puncture tests under oil indicate that the 60-cycle routine test, when properly carried, weeds out all the insulators which are likely to be a hazard under operating conditions.

The impact test is a very useful test on insulators also. In this test a large condenser is shunted by the insulator or insulators it is desired to test in series with a sphere gap. The latter is set to a setting somewhat greater than the flashover setting for the potential it is desired to impress on the insulator. The condenser terminals are connected to the terminals of the 60-cycle transformer and the voltage across it is raised until the sphere gap breaks over. It is essential in this case that the capacity of the sphere gap be small compared to that of the insulator, otherwise the initial flashover may take place across the insulator. There is, however no difficulty in obtaining proper operating conditions. The main difficulty is in determining the value of the impulse to which the insulator has been subjected. There is also, in this test the same danger which Mr. Lapp mentions of the arc localizing along a certain path, and melting the porcelain.

Mr. Lapp is, I think, in error in his assumption that the voltage surges to which an insulator is subject in service will equal in intensity the values obtained on test. It is quite possible to obtain conditions on test many times more severe than any that can be obtained in service.

Regarding the test recommended by Mr. Lapp, it has many good points in its favor. One is that the insulators are not flashed over and the testing equipment will not have as severe service as in the case of flashover. Another is the absence of the deafening noise accompanying flashover test, and the presence of large amounts of ozone which tend to produce headache.

A good feature of the method is that the value at which the test is made is under control. In the general run of suspension insulators, a certain test value may be found economic. For special requirements, a higher value may be necessary and for such cases, the batch may be taken from the standard batch by eliminating those insulators which fall below the test requirements. So far this is very good, provided that the purchaser of the special insulators agrees to pay a special price for his selected insulators. Otherwise, the purchaser of the standard insulator will have to bear part of the cost of the losses sustained in selecting insulators for more exacting service.

I think it very doubtful if this method of testing will be of any advantage for any other type of insulator than the suspension type. There are certain features in this method which make it very good when applied on a small scale, but on a large scale, there would be many disadvantages. The handling of large amounts of oil in vessels exposed to the air is, to say the least, unpleasant and may be hazardous unless the testing is done in an isolated fire proof building. Altogether, I feel that while electrically the method presents some good aspects, it should be carefully investigated before it is adopted.

It should be understood by all concerned that more severe requirements will most assuredly lead to more costly insulators. This may, of course, be economically justified, but it is well to point a warning so that the purchaser will realize that he is not going to get something for nothing.

Mr. Lapp knows that equally as good elimination up to a certain point may be obtained by methods in vogue. Whether a higher elimination will be justified is a question which depends on the worth of the increase in reliability to the user, because such elimination will certainly increase the cost of the insulator to the purchaser.

Lastly, there is some unpleasantness associated with the use of oil in testing insulators which, while not of paramount importance, makes it desirable to find something more convenient to use.

E. E. F. Creighton: Some of those present may not know that I started the oscillator test some years ago, and I have been waiting a long while for people to take it up. Now there are good reasons for that, the principal reason being that the main trouble with insulators could not be corrected by any of the electrical tests that we had in mind. The main trouble—ninety-nine per cent you might say, or maybe it is ninety per cent of the troubles—came from moisture in the porcelain. The moisture I should say in the cement causing a deterioration in the porcelain, and most of that deterioration was due to the absorption of the moisture.

That perhaps is not the major trouble, but the expansion of the cement itself. Cement has a property of expanding, as civil engineers have shown us, continually, if it is moistened and dried. Every time it is moistened it expands, every time it is dried it contracts; every time it is moistened again it expands a little bit farther, so that each time it gets thicker and thicker, until finally it so fills the space between the pin say and the porcelain, or between one porcelain shield and the other, that the natural temperature expansion will cause a crack in the porcelain.

Now as a matter of fact part of the trouble in recent years has been due to this expansion effect. Naturally, the test will not show that. There is a perfectly good porcelain insulator, when it leaves the factory, that has been broken by temperature effects. That fact, however, does not detract in any way from the desirability that Mr. Lapp has emphasized here of an over potential test. When we get rid of the large number of the troubles due to expansion of cement, then it seems to me it becomes necessary to make refinements of over-potential tests.

As Mr. Skinner has pointed out, any sort of test is going to eliminate—any sort of severity in test is going to eliminate more porcelain, and it has to be paid for; but I think it is a very good investment. The whole question, which has been under discussion for years, is what is a reasonable, proper test. The nearest we can come to it in my estimation is to say what are the strains put on an insulator in practise. The principal dielectric strain comes from lightning. Lightning may be of low frequency, but it is more liable to be of high frequency, therefore some transient test, or some continuous test with the higher arc-over value should be applied—some continuous test which is equivalent to a transient test.

The nearest I could see to the proper test was to apply a very sudden test, either by the oscillator or by the impulse test, which would be equivalent to lightning. There has been discussed many times the question of whether it does not damage the porcelain. Just to conclude the matter, compare this situation, an insulator that is tested equal to arc-over value, that porcelain, at the instant that the test ceased, may be at the point of puncture. It has been damaged, it would have punctured, say if the test had been continued a few seconds longer; therefore, there is a piece of porcelain that is damaged and put on the line. Now consider the over potential test, a test at say twenty per cent above arc-over values. That insulator may also be just ready to puncture when the test is stopped, but you have that factor of safety, enough to protect the insulator from lightning.

It seems to me therefore, that, finally, the standard test will be some form—and it does not make any difference to me personally—of over potential test as a perfectly proper test to put on the insulator.

C. P. Osborne: This matter of insulators to the operating men reminds me of the small boy who didn't know which school he wanted to go to. We will have four or five different salesmen come into our office and each of them will tell you the advantages and disadvantages of his insulator. One will tell you that porcelain must be thick, the next one will tell you it is in design, the next one will tell you that the curve is not just right—and the operating man is up in the air. I have been attending these conventions for about ten years, and as yet I don't believe the manufacturers agree on types of insulators. Of course, each manufacturer has his own ideas of these things, and each is the best according to his own ideas.

I have had considerable experience with insulators in a country where we have no salt air, but we have great differences in atmospheric conditions—a great deal of rain, then sunshine, then fog (of course it only rains once in a while in Oregon); but we have had considerable trouble with different types of insulators in our operation, and it seems to me that manufacturers and operating engineers are not close enough together. It is a serious problem. Right now we are endeavoring to build a line, and the economic question in building the line is what type and form of insulator to use. We have to calculate the cost from many angles to arrive at the economic figure for this. You can go to an expense which would be prohibitive. The operating man has to keep his expense down. The manufacturer must manufacture something that the operating man can afford to use, but the manufacturer must charge a price at which he can deliver an insulator that will give the operating man service. Service is the first thing we must get. Public service corporations are simply the tools of the public; you cannot give the public an excuse for a shutdown. They are educated to the point where you must give them continuous service, and when an insulator breaks down it is the least of their troubles. We can say, well the manufacturer thought he had insulators that would not break down. Of course, several reasons might cause the insulator to break down. The boys might shoot it, for instance; and sometimes small checks in the enamel will occur which allow moisture to get into the porcelain. These checks may not be visible to the eye without a magnifying glass. The reason for this I do not know. I don't want to place the blame on any one manufacturer; I find it on most any insulator we have, and we have several different makes.

I do feel that there is not enough cooperation between the operating man and the manufacturer. Somehow it seems to me that a change ought to be brought about through closer study of operating conditions. It is the same thing in operation as it is in manufacture. It may be that no two operating men will agree on the same subject; but we are vitally interested in this insulator game. I do feel great strides have been made in the manufacture of insulators in the last few years, and I am beginning to feel the weak spots in our system are not so much on the line as formally.

R. J. C. Wood: If it can be proved that we are going to get better insulators for the money, the proposed method of testing will be justified.

I agree with Mr. Fortescue as to the statement of Mr. Lapp that we will get surges in practise more severe than the highest test we would ordinarily put upon an insulator. If such a condition existed I would consider the line to be under insulated.

The whole matter is a question of economics. We will pay extra money for good insulators just so long as we get our money's worth and no longer. We have had some small experience with this testing device of Mr. Lapp's. They sent us out some of the porcelain to test and we tested a number of insulators. Many of the punctures that we got with this method of test were some little distance out from the cap, approximately half way between the cap and the outer diameter of the porcelain. Presumably, as Mr. Lapp suggests, the insulator was not designed for this particular form of test, and to meet the more severe condition imposed by this test the porcelain would have to be thickened out towards the edge of the insulator. Whether that would actually be required to take care of the stress that occurred normally on the line, I rather doubt. It might be putting material in a place where it was not necessary on account of line stress in order to make it pass this particular, special test. How-

ever, another few ounces of clay in the insulator does not amount to anything in the matter of cost. There has been a good deal of talk in the past as to the possibility of damaging an insulator by subjecting it to excess electrical tests—and presumably a feeling that an insulator can be tested with a certain potential of less than puncture value with resulting damage. Perhaps some of those present can tell us the nature of that damage, what it is that happens in the porcelain that takes some time to come to fruition.

On the Big Creek lines we have got quite a number of insulators —there are some 7000 towers, suspension towers with twenty-seven dead-end towers with one hundred and thirty-two insulators on each; and there is a great percentage of those dead-end towers, so there are a great many disks on the line. We have kept records of every individual insulator that is meggered and its location in the string on each line, each phase, *a*, *b*, and *c* on each tower, and the date and a few other things. All these data were taken for the last three years and punched on cards; then run through the machine and the information segregated in any desired manner.

The analysis of insulators that show low on the megger shows that in the suspension strings a vastly greater percentage of the top units proved bad, the ones nearest the tower. The first thought was, that in Southern California the sun which shines there has been shining on these top units on and off every day of course, and expanding and contracting them, and that is the reason why they have failed so much more than any others in the string. But we found that in the dead-end insulators which lie in a horizontal plane and all get the sun alike and the same thing is true, it was the one nearest the point of suspension at the tower which proved bad in the greater percentage. The one showing the next highest percentage was the one next to the conductor. Of the others there was nothing to pick, they all showed about an equal percentage of failures.

This at once began to have the ear marks of a mechanical failure. There is a good deal of vibration on these lines, and it was a sort of crack the whip performance, the one nearest the tower took the brunt of the shock. It seems that there is a great deal of room for research on the strength of porcelain and insulators under repeated alternating stresses. We are starting some work on this latter phase of the question and rigging up a small span about twenty-five feet long with a dead-end insulator at one end similar to the insulators on the Big Creek line, with a tension arrangement on the other end, so that this twenty-five feet of cable may be stressed to the same amount as the actual line. A motor driving an eccentric connected to the centre of the span will keep it in violent vibration back and forth. We hope to discover whether such a vibration has any effect upon any insulator, and whether it picks out the ones nearest the point of support in the same way that often happens on the line. If so, we will have started on the road to discovery of some of the causes of most of these failures.

There is need of an insulator of greater mechanical strength so that we can increase the size of our conductors. The amounts of power now transmitted are becoming so large that the corona limit is not going to be the determining factor in the size of a conductor but we will go above the corona limit of size in order to cut down line loss. And this all ties in with the question I raised before, as to whether it is not a mechanical weakness that is responsible for the greater part of these insulator failures.

Alan W. Eshelby: Mr. Wood has asked the question "What happens during the flashover?" I don't pretend to stand here and tell you what happens, but I would like to suggest a possible means of finding out what happens during the flashover. To the best of my knowledge, the method I will describe, is not in use commercially at the present time.

I have been interested for a number of years in photography and it occurred to me that the use of quartz in the camera in place of the glass lens might be of some advantage in photographing incipient corona. I therefore had such a lens ground and equipped my camera with it, but as I was not in a position to make standard laboratory tests I had to be content with taking photographs of flashovers on generators in actual service. I made these photographs using two cameras. One camera equipped with a standard Jena glass lens, the other equipped with a lens ground from natural rock crystal. Both shutters being arranged to operate simultaneously. In practically every instance there was no similarity in the photographs.

Quartz as you know, is transparent to the ultra violet end of the spectrum, while glass is absolutely opaque. The photographic emulsion is more keenly sensitive to the ultra violet end than the visible end. In fact the ordinary photographic emulsion is sensitive from approx. 3250 Å to 6000 Å and certain special emulsions have even a greater range.

The Westinghouse Company has developed for use in special tests, a high-speed camera which takes a series of photographs rapidly succeeding each other (not a motion picture camera) all exposures being made on one plate, unfortunately Mr. Legge, who designed the camera, has used a very cheap achromatic lens in this camera and I feel that here is a case where the quartz lens would tell an entirely different story. To those who are interested and wish to experiment along those lines let me suggest that they use natural rock crystal and not synthetic quartz, remembering that the speed of quartz is approx. seven times that of glass.

W. D. A. Peaslee: There are several points in Mr. Lapp's paper with which I believe it is necessary to take issue. The first sentence of his second paragraph is a little bit misleading, as he has not specified the frequency of flash-over voltage, or the frequency at which the impulse ratio is taken; obviously it would not be correct to use a flash-over and impulse ratio, taken at different frequencies in this way.

The last sentence of this second paragraph I agree with most heartily and believe that it cannot be too strongly impressed upon the manufacturers and users of porcelain insulators.

In regard to his remarks about the effect of immersing the insulator in oil for testing, I believe he has omitted the most important result of such an immersion; that is that the different dielectric constant of the oil distorts the flux, the dielectric flux producing an entirely different distribution over that encountered in air. On page 492 he makes the statement that the high-frequency test adds but a few per cent to the voltage available to test the dielectric strength of the insulator. I believe this statement is entirely unwarranted, as my experience in a good many years testing in this particular field, indicate that an increase in the neighborhood of 30 per cent can be so secured under constantly stable conditions.

The overpotential test discussed by Mr. Lapp is not at all new and while I do not know who originated it, I do know that it has been known to advanced workers in this field for ten years or more and has been abandoned by some of them for rather definite reasons, most important of which are that it protects the petticoats of the insulator from the searching effect of a high-frequency test and that it distorts the field around the insulator, making the test not at all representative of the conditions under which the insulator will be forced to operate on the line. I believe it is fundamentally wrong to run a routine test on any apparatus that is radically different in conditions from those which it will encounter in practical operation.

I am very much amazed at his statement that the insulator does not get hot under this test; as my experience of this test a good many years ago indicated a rather decided rise in temperature of the samples under test.

I am also very much astonished at the claim that the surface digestion of porcelain is due to a lack of penetration of the dielectric stress. I believe that it can be conclusively demonstrated that this digestion is entirely a temperature effect and is due to the extremely high temperature of the corona streamers. I

cannot conceive of any lag in the establishment of the dielectric field of an order of magnitude necessary to make this claim substantially correct and I believe that the heat absorbed on sustained high-frequency stress, is entirely an energy function, due to the characteristics of the porcelain as a conductor of the third class wherein the current voltage characteristic changes from a positive to a negative value at some particular current density. I do not believe the data available warrant the assumption that this phenomenon mentioned can be compared with the skin effect in a solid electric conductor. In regard to his specified limits, he states that when the overpotential test is applied instead of the above final tests, it removes the units most likely to fail in service, I would like to ask if he has submitted the units that have received these overpotential tests, to a subsequent high-frequency test, and if so what results were obtained.

I believe that fundamentally there is no such material as a true dielectric of dimensions greater than atomic distances. I can conceive of dielectrics such as a chain of hydrocarbon linkages wherein the displacement of electrons from their attending nuclei within the atom, could be transmitted over the space occupied by several atoms, but as the range of atomic forces is of the order of one Engstrom unit, I cannot conceive of a substance consisting of isolated atoms or molecules functioning as a true dielectric. It seems much more tenable that these insulating materials are conductors having a variable current voltage characteristic, which changes at some point from positive to negative and that their destruction, instead of being a dielectric rupture, is merely due to the fact that the current density has passed the critical voltage point and a further increase of current can result without an increase of applied voltage, or even with an attendant decrease in the voltage drop across the conducting path.

I believe if this theory is applied to the behavior of our insulating materials, a great many of the seeming discrepancies we are accumulating, will be explained and we can appreciate more exactly the fundamental mechanisms of failure of insulating materials under applied voltages.

G. W. Lapp: It is gratifying to hear a note of acceptance of the overpotential test, in principle at least, by most of those who have contributed to this discussion.

Practical economic considerations may set a limit to ones enthusiasm in actually applying such a test to his product but the demand for continuity of electric service should justify higher standards among users of insulators.

Definite improvements in the quality of insulators in the last few years have made it possible now to adopt this overpotential test as a routine test at a slight difference in price.

Among the various points brought out in the discussion no fundamental objection to the overpotential test has appeared.

Mr. Fortescue has noted some of the phenomena of the high-frequency and 60-cycle flashover tests and seems to be impressed with their severity but mentions the difficulty of obtaining values for the impulse effects. Admittedly the deafening and stupefying effects accompanying these flashover tests are extremely spectacular compared to the quiet intensity of a full wave overpotential test but it takes more than noise and ozone to puncture questionable porcelain. It is quite possible to take the units from those spectacular tests and knock out four to six times as many more by applying 120 per cent overpotential.

When flashover occurs on the rise of the 60-cycle voltage wave the heated path of the spark partly lets down the voltage for the remainder of the half cycle. The higher frequency oscillations are superimposed on a lowered base and the few fine peaks that rise from the damped train seem to have small power to puncture porcelain.

In assuming that the insulator in service may be subjected to a condition as severe as flashover test I had in mind a string of insulators with some of the units punctured. Lightning would then cascade the sound units subjecting them to full impulse flashover voltage. Mr. Fortescue has small respect for nature when he conceives that the flashover test is "many times more severe" than such a cascading impact.

Professor Creighton's estimate that over 90 per cent of the troubles in insulators are due to absorption of moisture by the porcelain is in harmony with the conclusion of the excellent paper by Farr and Philpott which is open for discussion. The porosity of porcelain may be due to improper materials, to underfiring or to overfiring and is by far the most subtle factor in insulator manufacture. Porous porcelain may be sufficiently low in dielectric strength to increase the losses by puncture even on the usual flashover test.

The most important function performed by the overpotential test is to eliminate most of this porous material before it is put on the line. As an ultimate safeguard against absorption we glaze our porcelain all over.

The evidence of destruction of insulators because of expansion of Portland cement in the joints is not conclusive. In fact the existence of numerous regularly spaced vertical cracks around the cement joint of pin type insulators appears to give direct evidence of shrinkage of the cement. From an examination of many old insulators including some unbroken glass insulators, through which these shrinkage cracks could be clearly seen, one would conclude that shrinkage of the cement rather than expansion is typical.

One of the insulators examined for these cracks was broken apart exposing the flat top of the second shell the surface of which was pitted because portions of the porcelain had been crumbled off and were found adhered firmly to the adjacent cement. This was an extreme case of disintegration evidently due to absorption of moisture and freezing. It gives some idea of the internal forces that may be present in porous porcelain which help the force of thermal expansion or contraction to crack the piece.

The crazing of the glaze on single fired bodies such as insulators is unusual, when crazing does occur as on dishes it is of a coarse pattern easily seen. It would seem that Mr. Osborne has detected a microscopic form of crazing that has hitherto escaped observation. Even devitrification would not be expected to occur in the type of glass used for insulator glazes.

When Mr. Peaslee comes to witness this test he will be dismayed to see the pittiless manner in which it punctures defects in petticoats and shells as mentioned by Mr. Wood. In fact it is preferable to seal the outer lips of the shell only to save the petticoats from puncturing. It might save years of misdirected effort if some of the advanced workers known to Mr. Peaslee would publish results of their tests.

The very moderate temperature rise exhibited by hard fired disks after several minutes application of 120 per cent of flashover voltage must be due to low losses both within the dielectric and in the corona enveloping the surface. For porcelain having an appreciable power factor the heat due to internal losses on this test is rapidly cumulative to quick puncture because there is no cooling medium as in the immerzed oil test to prevent a rise of temperature. The low temperature of the corona appears to be due to its intensity which causes a high degree of uniform ionization and high conductivity of the air. As the current traversing this low resistance corona is only the small charging current required by the dielectric the ohmic loss is probably very small. By preventing the hot concentrated flashover streamers the major source of heat is eliminated.

A number of units that had passed the over potential test were given the high-frequency test with maximum severity of application without puncturing any of them. The greater number of punctures caused by the overpotential test doubtless includes the same insulators as would be punctured by the 60-cycle and high-frequency tests.

DISCUSSION ON "POWER DEVELOPMENT ON THE COLORADO RIVER AND ITS RELATION TO IRRIGATION AND FLOOD CONTROL."* (MERRILL)

Vancouver, B. C., August 8, 1922

J. B. Fisken: One thought occurred to me when I read the paper and that is that we now have connection over the Idaho-Montana line through to Seattle, Tacoma, and I don't know just how far south, with a break between Tacoma and Portland, and some breaks in Oregon; and I don't think it takes any very great imagination to visualize the time when our plants in Eastern Washington will run in synchronism with plants on the Colorado River. It will not in any sense be transmission from Eastern Washington to Southern California, but it will be simply an interchange of current, our plants furnishing the load as required on the northern end and meeting the western Washington plants, the Oregon plants and so forth.

It is extremely interesting, and as far as I can see, extremely complicated. The question of ownership, of the lines, private, state or Federal, I think, is involved in this, and I am afraid that it is going to take a long time until development will finally take place.

DISCUSSION ON "220-KV. TRANSMISSION OF THE SOUTHERN CALIFORNIA EDISON COMPANY AND SOME 220-KV. RESEARCHES"† (WOOD),

Vancouver, B. C., August 8, 1922.

W. A. Hillebrand: Concerning the experiments on the disconnector switch, with regard to characteristic flash-over and the opening distance and clearance from the ground necessary to prevent the arc from shooting across the gap. Was any effort made to control the direction of flash-over by means of screens or guards which would reduce the gradient between the blade and the clip on the opposite side?

R. J. C. Wood: The only attachment to the switch is a vertical piece of pipe on the clip end which, when the switch was opened, formed, with the switch blade, a horn gap. This pipe was within three or four inches of the clip. The arc would very often hold onto this clip and pay no attention to the horn at all. There was no other attempt to influence the arc. The arc hung on for five or six seconds. We were satisfied that the arc was too long and that we had better not attempt to use such a switch for breaking charging currents.

W. A. Hillebrand: I think you misunderstood me, Mr. Wood, it is not in connection with the switch or breaking charge.

R. J. C. Wood: That was the charging current?

W. A. Hillebrand: Yes, but as I understood you to say, your disconnecting switches in the substation being 220, are mounted on the tripod that you had the nine-inch gap—linear gap necessary—a nine foot gap with regard to the striking distance to the ground, to prevent the possibility of an arc shooting across the open gap into the substation wire.

R. J. C. Wood: We had a big shield around the top of these posts, the circular disk to which the legs were attached was in the neighborhood of twenty inches in diameter, and formed a shield for the insulators distributing voltage in the same way that the shield on the transmission line does, it also prevented corona from the switch clip; but we did not try anything such as Mr. Hillebrand suggests. We were rather skeptical of any of these high-frequency effects existing at all. But we thought we had better make sure and arrange this side-gap so that if any of these unknown things did come in then we would be safe. In making the test we duplicated the set-up of the station, the walls, columns, etc., so that the field surrounding the switch would be the same in the test as it would be in the power house. Does that answer your question?

*A. I. E. E. JOURNAL, 1922, Vol. XLI, July, p. 500.

†A. I. E. E. JOURNAL, 1922, Vol. XLI, July, p. 471.

W. A. Hillebrand: Yes. One other thing which had better perhaps be discussed, that may be of extreme interest, and is of unquestioned importance, that is, the charging current of the line, the kv-a., its relation to the generator, the capacities available, the methods of energizing—of excitation, and finally of switch synchronizing. That is, you have to energize the line with presumably a very considerable potential difference between the open end of your line and the system at Eagle Rock, which you will have to parallel.

R. J. C. Wood: First of all as to the charging kv-a. on the line, that will be 50,000 kv-a. for one line, the whole distance. After once getting started, there will be no difficulty, the line can be cut up into sections. If we have to, when we first start we can energize a section at a time adding generators as required. Also, we will have synchronous condensers at the load end. It is quite possible to put a condenser on the line and with a generator on the other end, bring the whole system up together from standstill, having the condenser on the end reduces the kv-a. required from the generator. One way of looking at it, part of the required 50,000 kv-a. comes out of the generator, part of it out of the synchronous condenser.

Apart from the magnitude, I do not see why operating problems are going to be any different from what they are now. With lines paralleled at the generating end only, one has a higher voltage than the other at the load end, when one is carrying the load, the other is not carrying the load.

Upon paralleling at the load end, loads and voltages in the two lines will equalize. There will be surges of course but so far we have been unable to record higher than an 80 per cent voltage rise when cutting in or out a 100-mile section of line and if the line is not good for that it is not good for anything.

With regard to determining what these high voltages—surges—on the line actually are going to be, all that can be obtained is an estimate based upon what we actually have now on the 150-kv-line; we have been working for some time to determine what voltage rise—surges—occur on that line in normal operation. We have had a lot of experience trying to make a surge recorder. We finally rigged up a device comprising substantially six points, which formed six air gaps of different lengths, varying from about the 64th of an inch to one eighth of an inch. These points are opposite a metal plate, and a kodak film moves along in the gaps. We have arranged to use an ordinary standard kodak film, load and unload it in daylight, the substation man or anybody else can handle it.

But we have had records on the surge recorder of as much as something less than 100 per cent rise of voltage. Of course there is nothing very precise about it. The first gap is set to discharge at slightly above the line voltage—possibly 10 per cent; the second gap at 25 per cent above voltage, the third at 50, the fourth at 100, and the fifth at 200 per cent above normal voltage. The highest surges that we have any record of so far, occur when we kill the bus in the station where we have this recorder installed. We have records of surges which occur when oil switches are opened at the far end of the line. The recorder, by the way, is on the bus at Eagle Rock substation, and we get records of switching operations at Big Creek, on the other extreme end of the line, but so far we have no records of anything like 200 or 300 per cent above normal voltage, which voltage would still be insufficient to flash-over an ordinary string of insulators.

We have been troubled with unexplained flash-overs on the Big Creek line. This has occurred at times when operation is apparently entirely normal. No switching is going on, fair weather, apparently no reason at all, the first thing we know there is a flash-over and the voltage is down and we are in trouble —which does not last very long, about from one to two minutes; but at the same time the larger the system becomes and the greater amount of power that is going over the line, the more serious, even what we call a momentary interruption, becomes. We are bending all energies now to try to determine what is

actually going on in the present line, and we feel that until we get the answer to that we will not have the answer to the flash-over.

J. Mini, Jr.: Through the courtesy of Mr. Wood I had the opportunity of visiting and seeing the tests made on his system during the time they had on the high voltage, and I feel that there have been very few tests ever made—probably none ever made, of a line of such high voltage and that length on an actual transmission line. When the line was operating somewhere around 280,000 volts it was noisy and visible at night. The fact that the line was alive was easy to detect while it was operated with above voltage, but when the voltage was brought down to 220,000 volts you would have to be told that the lower voltage was on or you would not be aware of it.

There are one or two points in connection with Mr. Wood's paper where he tells you that the transmission line source is from star-grounded transformers and the receiving end connected to delta-delta transformers. He also tells you that they break these flash-overs by lowering the voltage. I believe that when we come to connect both ends of the transmission system star-grounded, that is the receiving end and the sending end, it will not be so easy to break the flash-over as it is under their present system where the receiving end is connected delta. I speak from our experience of 110,000-volt transmission lines where the receiving end is connected star-grounded as well as the sending end, and it is only in the case where we have one generator on the line and the energy is small that a flash-over can be broken, that is, the arc can be broken by lowering the voltage at the generator's end. The flashover arc is fed from both ends, whereas in Mr. Wood's system at the present time the real energy current in the flash-over arc to ground comes from the sending end.

We have found that the best method of getting rid of these flashovers, when they happen, (of course this can only be done when you have duplicate transmission lines operating in parallel) is by having one relay that is set very light for ground trouble, and three other relays set heavy so far as trouble between phases goes, you can have this line severed from the system at the receiving end and sending end in ample time before any damage is done.

Before we put in this system of residual relays which trip a line out with a moderately light ground, a flash-over to ground on our lines burned them down invariably. It was practically impossible, with hand operation for the operator to disconnect a line in time, before the wire had not been so severely damaged by burning that it subsequently pulled in two.

There is just one other point that comes to mind in regard to operating these lines at very high voltage and long mileage, and that is, if you have duplicate lines, and say one line is fully loaded and you want to switch in a second line, there will probably be a very large phase angle at the receiving end between the loaded and empty line voltage which will cause a severe disturbance of the voltage while equalizing the load by throwing them together. It has occurred to me that it might be possible in this case to close the line at the receiving end first and back voltage to the power house; then put on a separate generator and pull up some of the load and finally parallel the lines at the power house after the load was more equally divided over the two lines.

F. W. Peek, Jr., (by letter): Mr. Wood gives some very interesting and important data on the various factors affecting transmission at 220 kv. Mr. Wood's conclusions are not based on laboratory work alone but also upon the several years operating experience of the Southern California Edison Co. at a 30 per cent lower voltage. No radical changes in types of apparatus have been found necessary.

Standard ten-inch disk insulators will be used. The use of a simple metal ring shield will reduce the maximum unit stresses below those on present successful lines operating at lower voltages. The ring shield also serves as a very efficient arcing ring. Tests at 280 kv. on a thirty-mile section of line indicated that the line insulation will be quite satisfactory. There was only one arc-over. This occurred on a nine-unit string at 280 kv. during the first rains after the insulators had had a chance to accumulate dust for a full season. This is probably the worst condition to contend with in California. In connection with the arc-over of wet and dirty strings I wish to point out that unless the power supply is large, laboratory tests are of little value as an indication of arc-over voltages in practise. This follows because when the power is limited by the generator or transformer the heavy current flowing over the conducting surfaces lowers the voltage before an arc develops. The arc-over voltage thus appears much higher than would actually be the case on a large system.

The neutral of the system will be thoroughly grounded and thus eliminate dangerous oscillations and high voltages in case of an accidental ground on one or more lines. The permanent grounding of the neutral at the transformer also makes possible a much safer and better transformer. In fact, all creepage surfaces in the transformer are eliminated.

I am particularly interested in the corona measurements, because these measurements check so well with my own made on an outdoor experimental line in Schenectady in 1910 and discussed in the TRANSACTIONS.

It is interesting to make a comparison. In the Schenectady work it was also found that when a line had been idle and had become wet or dirty the loss was quite large on the first applica-

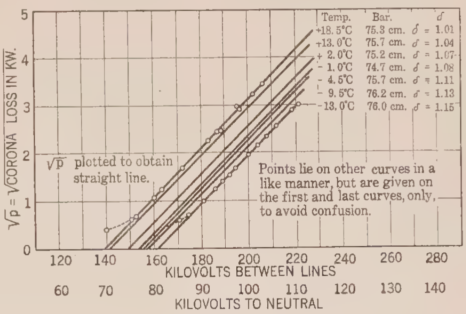

FIG. 1—CORONA LOSS MEASUREMENT AT VARIOUS TEMPERATURES

3/0 Seven Strand Cable. $r = 0.59$ cm. $S = 310$ cm. Single phase 60 cycles—1.09 km. Total Conductor Fair Weather.

tion of voltage. It was at first thought that this was due to leakage over the insulators. Tests were then made with a great many insulators bunched together so as to practically eliminate the line. It was found that the insulator loss was negligible under the above conditions and also in very heavy rain and snow storms. The excess loss was found to be due to the wet or dirty conductor surface. A study in the dark showed that water was sprayed from the conductor with a considerable increase in corona which extended out a great distance from the conductor surface. When there was fog, rain, snow or sleet this condition was found to be continuous.

In the formula for the disruptive critical voltage there is a factor, m_0, called the irregularity factor. This factor is used as a measure of the effect of roughness or irregularities of the conductor surface in lowering the critical voltage. It is unity for a smooth cylinder and less for cables. It is, therefore, not much affected by temperature and is constant for any weathered conductor. In fact, we found m_0 constant over a range of hot summer temperatures to below zero temperatures of winter, (See Fig. 1). Fog, rain and other conditions lower the critical voltage in the same way.

The weather factor, which may be called m_s, is variable. An average value of m_s for storms is 0.8. Mr. Wood has combined m_s and m_0 in one factor and denoted it by capital M_0. Thus $M_0 = m_0 \, m_s$

I rather think it undesirable to do this because small m_0 is a

constant which applies to a given weathered conductor anywhere, while m_s will vary with the location and the season. Mr. Wood shows an apparent variation of capital M_0 with temperature in Fig. 27. Upon examination it is found that the stormy weather points occur at the lower temperatures. I am inclined to believe that the apparent reduction is not due to the lower temperature but mostly to the storms or fog that occurred at the lower temperature. It will be noted that the fair weather points in Fig. 27 can be equally well represented by a line parallel to the temperature axis at 0.85 and the stormy weather points by a line parallel to the temperature ended at 0.80 (See Fig. 3).

Then Fair Weather $M_0 = m_0 = 0.85$

Stormy Weather $M_0 = m_0\, m_s = 0.80$

The average storm factor for the particular tests is therefore:

$$m_s = \frac{0.80}{0.85} = 0.94$$

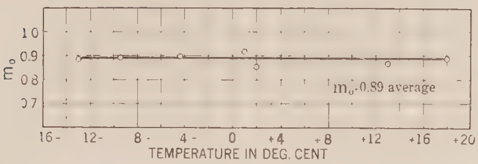

FIG. 2—3/0, 7-STRAND CABLE $r = 0.59$ CM. $S = 310$ CM. SINGLE PHASE—60 CYCLES—FAIR WEATHER

This factor on a long line would be the average of the various conditions along this line from dry weather to heavy storms. The apparent variation of capital M_0 with temperature would probably be quite different for different seasons in a given locality and for different localities. The variation of M_0 in Fig. 26 can be explained in the same way. It will be noted that the low points occur at the low temperature and are for the most part taken at night when fog is likely to occur. The variation of individual points at approximately the same temperature is also quite great at this time of day. For example, the variation of M_0 for 15 deg. to 17 deg. temperature for 12 A. M. to 4:30 A. M. is from 0.80 to 0.90. The shot gun effect of these diagrams should be expected for a long line where all of the variables are not under control or known. The starting voltages vary

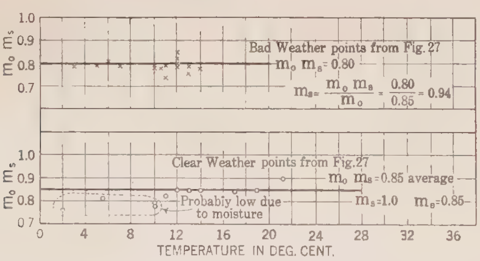

FIG. 3—BAD WEATHER AND CLEAR WEATHER POINTS DATA FROM FIG. 27

along the line and the meters record an average condition. Part of the individual variation is also due to the fact that the values were obtained at the lower or unstable part of the curve.

The above discussion is given as a possible explanation of the apparent variation of M_0 with temperature which Mr. Wood has found. It is not intended as a criticism of the value of the data. Such measurements on operating lines are of great value and the industry is greatly indebted to Mr. Wood.

Referring now to the m_0 factor as originally employed, it is desirable to obtain conductors in which this is as nearly unity as possible. It is necessary to give this factor greater consideration as the voltages are increased. A smooth cylinder would be a desirable conductor. Since in present practise cables are employed it is of great importance that the individual strands be regularly placed and free from burrs and points and other irregularities of manufacture. The loss near the critical voltage on a new cable will often be higher than on a cable that has "weathered" under the action of voltage when there is a tendency for the burrs to disappear by oxidation at the over-stressed points. In making measurements on new cables of different stranding we have found high losses near the critical voltage where strands had been mutilated in manufacture.

It may be of interest to point out further possible irregularities in manufacture that will affect M_0. The Southern California

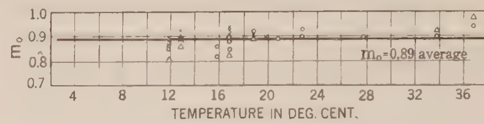

FIG. 4—M_0 VALUES—IRREGULARITY FACTOR OF THE CABLE SURFACE

Data taken from Table I—*Electrical World*, May 6th, 1922, also included Fig. 26.

Points indicated by x are bad weather points divided by an assumed average bad weather factor, $m_s = 0.95$ to reduce to m_0.

Points indicated by o are fair weather points calculated from data given in the table.

Points indicated by △ are points calculated by Mr. Wood where they do not agree with the x or o points.

x Storm points in table divided by $m_s = 0.95$.

o Fair weather points from data in table. $m_0 = \frac{m_s\, m_0}{m_s}$

△ Given when Mr. Wood's calculations do not agree.

Edison conductor which is highly satisfactory for 220 kv. is made up of individual strands about one-tenth of an inch in diameter. A single strand would have corona at very low voltage. In the cable each strand is placed around the surface as its neighbor is placed. Corona starts at a very high voltage because each strand shields its neighbor and the stress is divided equally between them. If, in the process of manufacture, one strand becomes squeezed out so that it stood above its neighbors it would take more than its share of the stress and local loss would occur at a lower voltage.

In conclusion I wish to again express my appreciation of this paper and to point out that it further confirms our belief in the success of 220-kv. transmission.

R. J. C. Wood: Mr. Peek's criticism of the use of the symbol capital M_0 to include the combined effect of surface roughness and weather conditions is well taken. It should be remembered however that the whole investigation was primarily undertaken to determine the constants of a definite line already built in a definite location, and that for this purpose the single factor answered the purpose. Sufficient data are given so that those interested may further split up this factor as desired.

There seems to have been some misunderstanding of Fig. 26 and 27. Fig. 26 gives the results obtained experimentally while operating at 161 kv. to neutral. The observations were taken every two hours, and from the measured loss, the physical constants of the line, and the atmospheric data, that value of M_0 was determined which would in each case satisfy the other conditions. A casual glance at the plot of M_0 against temperature shows that the two increase and decrease together, although the air density factor has already been allowed for in the calculation of M_0. The diagram is somewhat of the shot gun variety, and had average values of M_0 for each degree Centrigrade been plotted a much better looking result would have been obtained but at a sacrifice of sincerity. In Fig. 27 values of M_0 are plotted after having been determined from observations taken in both clear and rainy weather while operating at 141 kv. to neutral. No claim is intended that these values of M_0 bear any relation to temperature in fact the diverse weather conditions would preclude such an idea at once, but; for comparison, the line of Fig. 26 is extended through Fig. 27 as an indication of what might be expected to be the values of M_0

in clear weather at the lower temperatures, and to show the extent of the deviation from the fine weather line, caused by rain.

In Mr. Peek's replot of Fig. 27 in his chart No. 3 he has compressed the vertical scale so that a direct visual comparison of the two charts is difficult to make. His suggestion that the low temperature observations in his Fig. 3 are probably due to moisture is I believe not tenable as in this country such temperatures as 2 deg. cent. are only obtained with clear skies and unimpeded radiation.

Since reading Mr. Peek's discussion I have gone over the original data very carefully, together with U. S. Weather Bureau reports, and have selected a number of observations about which

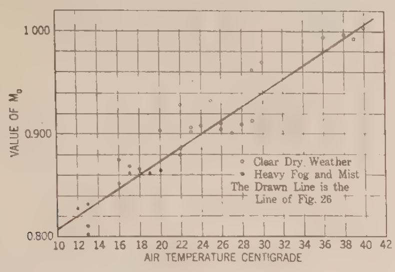

FIG. 5—OBSERVED VALUES OF M_0. 19.5 AND 12 MILES OF LINE, 161 AND 156 KV. TO NEUTRAL, 50 CYCLES

there is apparently no doubt as to absence of fog and including readings upon 12 miles of line taken at high temperatures. These are plotted in the accompanying Fig. 5 as clear circles. In the same figure are plotted a number of observations taken in heavy fog and mist but not rain, these showing in full circles. Apparently there is no discontinuity between the fair and foggy weather data and this would indicate that it is temperature and not fog that determines the variations of M_0 for this line.

In most of the published data upon corona loss measurements a suitable value of M_0 has been chosen and the loss, as calculated assuming this M_0 to be constant, shown in the familiar parabolic curve, observed losses have then been plotted lying more or less

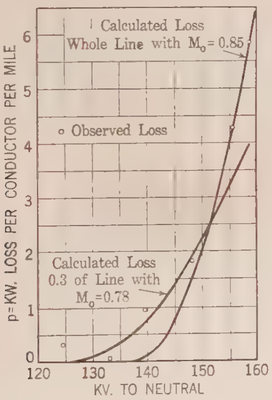

FIG. 6—CORONA TEST, 19.5-MILE LINE, 11 DEG. CENT., BAR. 72 CM. 50 CYCLES, OCT. 12/21

along the curve. The value of M_0 is chosen so as to place the calculated line well through the observed points in the upper part of the curve at high voltages, and the lack of agreement at below the visual corona point assigned to the dark realms of probability.

From a practical standpoint it is precisely the sub-visual region that is the most interesting. A transmission line cannot be expected to have a corona loss in accordance with the quadratic law until there is sufficient corona upon it to smooth out its roughnesses and this seems to be at about the visual point. This is illustrated in Fig. 6 in which is shown the observed losses of the test of Oct. 12, the data being in Table VII. The drawn lines show calculated losses, first assuming the whole line to have an irregularity $M_0 = 0.85$ which agrees well with the observed data above the visual point, and secondly assuming three tenths of the length of the line to be in corona with a factor $M_0 = 0.78$ which agrees with the observed losses below the visual point.

It seems logical to conceive of the line as having certain portions rougher than others and consequently having a lower value of M_0.

It should be remembered that in all the calculations of this paper the mean logarithmic spacing of the conductors has been used equal to 1.26 times the spacing between adjacent conductors. If on the contrary the spacing between adjacent conductors be used in the calculations, larger calculated values of charging current and higher values of M_0 in the corona formula will result.

DISCUSSION ON "EXCITER INSTABILITY"* (DOHERTY), Vancouver, B. C., August 10, 1922.

W. A. Hillebrand: A rather startling instance of an oscillation such as Mr. Doherty has just described, came within my observation some three years ago. There was a two-pull electro magnet for a Paulson high-frequency arc converter, the magnet weighing approximately 30 tons, and they had only 5-kilowatts of arc converters at the station. Now the magnet itself was perhaps the most powerful that was ever delivered, and it was excited by a 250-kw., 500-volt d-c. generator, direct connected to a 2400-volt induction motor. Now what happened was that the power went off. The energy stored in the magnetic field was sufficient to stop the motor-generator set, reversing it. This reversal of rotation of the motor generator demagnetized the magnet, magnetizing it in the opposite direction, and again brought the set to rest. That is, there was a highly damped oscillation of very low frequency lasting for a cycle and a half. We ran saturation curves under various conditions, and finally after the last run the current was cut off, and I think some three or four minutes after the machine was completely disconnected, while we were stripping it, we still got an arc, showing the current was still flowing. That is, it took several minutes, due to the very slow decay before the current came to zero.

R. J. C. Wood: This question of exciter instability and the results shown in the paper seem to make a pretty good argument for the individual exciter direct connected on the generator shaft. That is a type of construction to which we are going with our latest large units. When the construction is in that form the exciter can be properly designed to meet the conditions of the generator, and so on, so it will not be working on the low portion of the saturation curve.

While it is not an illustration exactly of exciter instability, yet this calls to my mind the conditions that exist when there is a long transmission line connected to a generator and the generator becomes self-exciting due to the charge on the line. You then get an instability not because the exciter is unstable, but because the whole excitation of the machine is unstable. A certain definite voltage on the transmission line causes a charging current of a certain definite magnitude to flow, and that current leading the voltage excites the armature and the field exactly in an opposite direction to the ordinary demagnetizing effect of a lagging load, consequently if the voltage produced by this exciting current is greater than that necessary to produce the current which caused the excitation, the machine will build up until saturation of the iron causes a balance.

G. F. Brown: Mr. Wood raised the question of the saturation curve. Where a voltage regulator is used, and machines are operated as they are on these large transmission systems, they require a broad range of regulation. A considerable margin in voltage over your operating point of exciter voltage is required, which in general means that you must operate all these machines lower on the saturation curve.

*A. I. E. E. JOURNAL, 1922, Vol. XLI, October, p. 731.

There are some points in this paper on the question of application that bring out the point that more attention should be paid to the application of exciters. For instance, in large steam turbine stations in the east, where there are no extensive lines attached, the results indicate that we should use compound-wound machines. Perhaps I had better carry that a little further. On a system such as you are operating in the West, on long lines, a compound wound exciter has some disadvantages. For instance, the point Mr. Wood spoke of, under conditions of self-excitation it is difficult to carry the regulation of voltage down as low as you would like. In conditions of run-away, it is impossible with the series field on the exciter unless you have a lot of applications in the way of voltage relays and devices for switching resistance into the circuit. It would seem that the simplest application i, e. broad range regulators, shunt-wound exciters, would be preferable for such cases.

R. E. Doherty: I agree with Mr. Wood that for large, important generating units the individual exciter is preferable. There are, of course, the well known points of controversy as to whether a direct-connected exciter is preferable to one driven by other means; not with respect to stability of operation, but to freedom from shut-downs. But, whether direct connected or separately driven, the individual exciter is, in my opinion, preferable.

I agree also with Mr. Brown that there are instances, such as he mentions, where shunt-wound exciters may be preferable to compound-wound. It simply means that in such cases, other considerations, deemed more important, make it necessary to sacrifice the inherently stable feature possessed by the compound exciter.

DISCUSSION ON "THE DEVELOPMENT OF TELE-PHOTOGRAPHY"* (ISAKSON),

Vancouver, B. C., August 11, 1922

R. J. C. Wood: Isn't the picture as received shown at Fig. 8 (D). I think that is actually what the receiving end gets over the wire and any exercise of imagination, as Mr. Hillebrand says, refers to (F). It would seem to me that these boundaries are determined by the co-ordinates of points along them, all around the boundary. That being so you then get these contour lines as shown on Fig. 8 (E). They are filled in with the particular shade according to one of the letters in the code corresponding to that boundary. You then get the Fig. 8 (E) as the final result received at the receiving end. The illustrator knows that nobody looks exactly like (D) and he makes it look a little better, like (8-F). Tele-photography means to a photographer taking very far distance scenes with a lens of long focus. Is this term telephotography standard in this sense of transmitting photographs to a distance by wire? The term is already fairly well assigned to the photographic science, and it would seem to me that some such title as photo-transmission or an equivalent would describe the process better than telephotography.

D. I. Cone: In that connection I note that the artist states "Under the second head which may be generally termed telephotography"—from which I gather that he is not satisfied that his word covers the subject. There are in the paper a number of references to the difficulties that have been encountered by workers on account of the inherent characteristics of the wire line. It seems to me that this is a hang over from earlier days when the transmission of signals over long electrical lines was less understood than it is now. As an example he states, "Interruptions to the circuit take place at an average speed of 250 times per second, a fact that renders its use on ordinary telegraph lines impossible since the relays in general use are of a low-speed type." That, while entirely true, is becoming less and less a limit, in fact it simply suggests that since he wants to use frequencies of the order of two or three hundred cycles per second he needs the telephone line as opposed to the ordinary telegraph circuit, or, what is equivalent to the same thing, the more recently developed carrier telegraph circuit which by merely modifying the terminal apparatus to handle higher frequencies is capable of caring for the high frequency on which his voids hinge. The earlier methods described in the paper can be said to have other difficulties at the present time entirely in the transmitting and receiving apparatus, and the question of troubles due to inductance and capacity on the line may be dismissed; and they say it is a bugaboo which can be most thoroughly taken into account to any degree of refinement that is necessary merely by spending a certain amount of money on it.

*A. I. E. E. JOURNAL, 1922, Vol. XLI, November, p. 811.

D. W. Isakson: As regards a name for the science of transmitting photographs over electric circuits I can only say that in this paper I havereverted to the term generally used and accepted by the technical and semitechnical press. An analysis of the word justifies its application. But as Mr. Wood points out it at present designates a division of photographic art and its inappropriateness therefore is not to be argued. It is to be expected that with the future development of the art appropriate nomenclature will be invented.

In the synopsis of this paper I have made the assertion that the solution to this problem of telegraphing pictures is near at hand. I have given no space to suggestions as to how this is to be accomplished. That the vacuum tube and carrier wave will play important roles in the development of picture telegraphy I have not the least doubt. In fact I am convinced that only by application of the carrier wave can it be made practicable, excepting perhaps radio. In this I have myself made some interesting experiments and hope to announce results in near future. Now as to Mr. Cone's suggestion of using telephone lines as a means of avoiding the difficulties encountered with low-speed relays, let me remind him of the telephone companies strict rules regarding the connection of foreign apparatus to its circuits. Neither is the low speed relay the insurmountable obstacle to success. It will be noted that in the Belin process and Lieshman's second system no interruptions take place. Here the current is continuous but varying in intensity. For this the vacuum tube relay has been used. The prohibitive cost of the arrangement with telephone and telegraph companies render both these systems impracticable from a purely economical standpoint. If by carrier wave we can send five or six photographs simultaneously and for the cost of, say two (allowing for added cost of apparatus) then we shall have taken a long stride toward ultimate success.

DISCUSSION ON "A GRAPHIC METHOD FOR THE EXACT SOLUTION OF TRANSMISSION LINES"* (HOLLADAY), AND "THE ELECTRICAL CHARACTERISTICS OF TRANSMISSION SYSTEMS"† (DWIGHT)

Vancouver, B. C., August 10, 1922

R. J. C. Wood: Again we have an illustration of how, in different parts of the world, and at the same time, the same ideas arise simultaneously. The curves shown in this paper (Dwight) are—I think if you turn the diagram right over, or the wrong way up, according to who is talking about it, that it will be found to be very similar, if not identical with the curves to be shown in the paper by Mr. Holladay. That paper shows a diagram which represents the exact hyperbolic equations.

When it comes to the purity of the English language, doesn't equation simply mean that two things are equal, and if we have an approximate equation, why shouldn't we be satisfied to let it go at that, and not call it a formula. We have equations, I believe, which are expressed in the form of—well, suppose A equals B, plus or minus something, which represents the errors of observation of something else, I think that is still an equation, without calling it a formula. The dictionary states that a

*A. I. E. E. JOURNAL, 1922, Vol. XLI, November, p. 807.
†A. I. E. E. JOURNAL, 1922, Vol. XLI, October, p. 727.

formula is a rule or principle expressed in mathematical language. An equation denotes the equality of two mathematical expressions.

J. R. Dunbar: The diagram in Fig. 2 of Mr. Dwight's paper shows reactive kv-a. in a circuit where the current leads the voltage, plotted upward, that is, kv-a. is plotted counter-clockwise with respect to kilowatts. The A. I. E. E. Standards, Section 3230, recommend that, in any vector diagram, the leading vector be drawn counter-clockwise with respect to the lagging vector.

The above rule is universally followed for vector diagrams involving volts and amperes. Although the apparent power is not strictly an alternating quantity admitting of vector representation, it is convenient to consider it a vector.

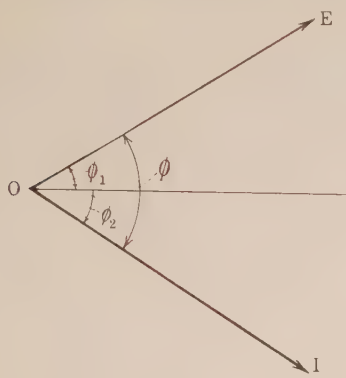

Fig. 1

It is the usual custom when referring to kv-a. in a circuit to talk about "leading" kv-a. when the current is leading the voltage. If, then, kv-a. is considered as a vector, leading kv-a. must be plotted counter-clockwise from kw. in order to be consistent with Rule 3230. If apparent power is not considered as a vector, there is no justification for drawing any vector diagram of apparent power.

Section 3238 of the Standards defines volt-amperes as the product of the r. m. s. value of the voltage by the r. m. s. value of the current. If volt-amperes be considered as a vector, it is convenient to have a method of computing the vector value. The expression which at once suggests itself is $\underset{\cdot}{E}\,\underset{\cdot}{I}$, when $\underset{\cdot}{E}$ and $\underset{\cdot}{I}$ are the vector values expressed as complex numbers.

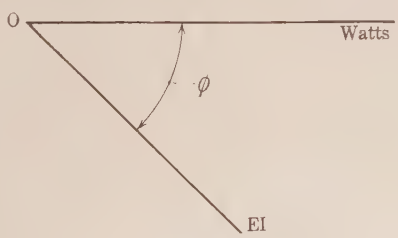

Fig. 2

In a case such as is shown in Fig. 1 where $\underset{\cdot}{E} = E\,(\cos\phi_1 + j\sin\phi_1)$ and $\underset{\cdot}{I} = I\,(\cos\phi_2 - j\sin\phi_2)$ the expression $\underset{\cdot}{E}\,\underset{\cdot}{I}$ is very cumbersome and difficult of interpretation, because the real part is not equal to the watts. The use of the numbers conjugate to $\underset{\cdot}{E}$ and $\underset{\cdot}{I}$ simplifies this computation considerably.

Two complex numbers are conjugate to each other, as defined in elementary works on algebra, when they differ in the sign of the imaginary part only.

If the current is multiplied by the conjugate of the voltage, the expression $E\,I\,(\cos\phi_1 - j\sin\phi_1)\,(\cos\phi_2 - j\sin\phi_2)$ is obtained. This reduces to $E\,I\,(\cos(\phi_1 + \phi_2) - j\sin(\phi_1 + \phi_2)$ or $E\,I\,(\cos\phi - j\sin\phi)$.

This is an expression for volt-amperes, for its effective value is equal to the volt-amperes of the circuit as defined by Rule 3238. It is in a much more useful form than if the conjugate had not been used, for the real part is equal to the watts, and the imaginary part is equal to the reactive volt-amperes, as shown in the foot notes to rules 3242 and 3246. Also the vector volt-amperes, in a circuit wherein the current lags the voltage, is plotted clockwise from watts, as shown in Fig. 2 which corresponds to the assumption made above.

If instead of the above procedure, the voltage were multiplied by the number conjugate to the current, as is sometimes done, the resultant expression reduces to $E\,I\,(\cos\phi + j\sin\phi)$. This is also an expression for volt-amperes, but it requires that the kv-a. in a circuit wherein the current lags behind the voltage be considered as leading kv-a. in order to be consistent with Rule 3230, which is not in accordance with the usual custom.

When the current and voltage are in phase, if either be multiplied by the number conjugate to the other, it is readily seen that the resultant expression is a real quantity; that is, watts.

It is to be hoped, therefore, that Standardization rules will be added defining volt-amperes as a quantity capable of vector representation for use in transmission line diagrams, etc. and giving rules as to the proper method of plotting volt-amperes.

H. B. Dwight: Mr. Dunbar's demonstration that a transmission line circle diagram should follow Standardization Rule 3230 for vector diagrams, is interesting and convincing. A diagram showing kw. and leading and lagging reactive kv-a. is to all intents and purposes a vector diagram, and Rule 3230 explicitly applies to *any* vector diagram. It would be inconsistent to draw a diagram of a certain shape to express a set of relations between currents in a transmission system, and then draw a diagram of a different shape to express the same set of relations between kv-a. which represent exactly the same currents.

The use of conjugate numbers, which are very advantageous in many calculations, does not require that the above conclusion be changed, but merely that the conjugate of the proper numbers be taken. Where the conjugate of an impedance is required, no difficulty is encountered.

The use of conjugates is both easy and natural. It will be remembered that a complex fraction is multiplied above and below by the conjugate of the denominator, in order to rationalize the denominator. In a somewhat similar way, when multiplying a complex voltage by a complex current, if the conjugate of the voltage is used, the resulting expression can be used to represent the volt-amperes, with the additional advantage that the real part is equal to the watts. It is necessary to use the conjugate of the voltage in order not to conflict with Standardization Rule 3230, but this can easily be done.

While the most usual and general problem is the multiplication of a voltage by a current, the matter is very clearly set forth by an example of a complex value of current $I\,(\cos\theta + j\sin\theta) = Ie^{j\theta}$ and an impedence $R + jX$. The voltage across the impedance is $Ie^{j\theta}\,(R + jX)$, and the conjugate of the voltage is $Ie^{-j\theta}\,(R - jX)$. If now, in accordance with the previous paragraph, the conjugate of the voltage be multiplied by the current, the resulting expression for v - a. is $Ie^{j\theta}\,Ie^{j\theta}\,(R - jX) = I^2R - jI^2X$. It is seen that the real part is equal to the watts and the unreal part is equal to the reactive volt-amperes, which are negative when lagging, thus agreeing with Standardization Rule 3230.

If, on the other hand, the conjugate of the current be multiplied by the voltage, as is sometimes done, the resulting expression for v-a is $Ie^{-j\theta}\,Ie^{j\theta}\,(R + jX) = I^2R + jI^2X$. In this, the lagging quantity is positive, and would be plotted in a counter-clockwise direction with respect to the in-phase quantity. This is in disagreement with Standardization Rule 3230, and so the procedure of using the conjugate of the current should not be followed.

Since both methods described have been used in publications, it is desirable that a decision be made. A phrase could be in-

serted in Rule 3230 of the Standardization Rules of the A. I. E. E. stating that it applies also to the diagrams involving volt-amperes.

S. Barfoed: Referring to Mr. Dwight's paper and statement regarding transmission line problem, given in Fig. 5 of F. G. Baum's paper on "Voltage Regulation and Insulation" JOURNAL of the A. I. E. E. August 1921, page 648, it should be understood that all diagrams and computations were made as simple as possible for the sake of explaining the general nature and solution of the long distance high-voltage transmission problem by means of synchronous condensers at the receiving end as well as at intermediate points at nearly uniform intervals along the line. Studies which we have been making seem to indicate that condenser stations should be placed at intervals of about 100 to 150 miles, provided that the voltage is not less than 220,000 volts and that economical powers are transmitted of the order of magnitude of 150,000 to 175,000 kw. per 3-phase circuit. Kelvin's law must here not be forgotten.

If power is transmitted a distance of 300 miles I would by all means advocate any solution which is accurate, but not more so than the nature of the problem demands. A diagram which has been in use in our office for years for solving transmission line problems for lines from 100 to 200 miles in length, is shown in Fig. 1. It is no different from that given by Mr. Holladay and more easily understood by most engineers. The accuracy is all that may be desired for lines of that length.

The basis for the construction of the diagram was given by Mr. Baum 22 years ago (see A. I. E. E. TRANSACTIONS, pp.412-422, May 1900). I am glad to see that both Mr. Dwight and Mr. Holladay have adopted this same circle diagram, although they arrive at its construction by the use of the functions of the hyperbolic angle. Mr. Holladay's diagram is exactly of the same form as one of several gotten out by me and published in the *Pacific Service Magazine* several years ago. In these diagrams the constants of step-up and step-down transformers were taken account of, as well as the influence of the charging current.

The diagram may be constructed quickly and accurately as follows:—

Direction $O\,a$ is vector of reference. Distance $O\,a$ = 100 per cent = constant and equal generator and receiver voltage for all loads. Swing arc $a\,f$ which is then the locus of end of generator voltage vector for all loads.

At no load the Ferranti effect is represented by the triangle $a\,b\,c$, in which $a\,b$ is the resistance pressure and $b\,c$ the reactance pressure caused by the charging current flowing over ½ of line resistance and ½ of line reactance, including transformer, etc. Now load the line with a load of unity power factor, $c\,d$ is then the resistance pressure caused by the power current flowing over all resistance in series and $d\,c$ the reactance pressure caused by the power current flowing over all reactance in series. $e\,c$ is the resultant and is the impedance line for full load with unity power factor of load. The triangle $c\,d\,e$ is made up of as many triangles as is required to include all pieces of apparatus and the line between the generator and the receiver over which the power current flows in series.

If no attempt were now made to hold the voltage constant, a line drawn from O to e would represent the generator voltage required at unity power factor of load; at a power factor of 95 per cent it would be represented by a line from O to f'''; at 85 per cent by $O\,f'$, and for constant kv-a. of load by $O\,r$, etc. For other loads than full load the quantities are referred to the respective load lines. By causing a quadrature leading current to flow over the reactances, a voltage drop may be compensated for, and by quadrature lagging currents, voltage rises may be compensated for. A synchronous condenser will perform such service when placed in parallel with the load; that is, it acts as a variable condenser for excitations above normal and as a variable reactor for excitations below normal.

If one were sure of the exact numerical value of the load power factor for any load, then it might be of some value to know with mathematical accuracy the particular quadrature currents needed for each load condition.

A very small change in power factor, however, will demand an enormous change in condenser capacity, by far outstripping any small error in the determination of the Ferranti effect represented by the small triangle $a\,b\,c$.

To the left in the figure, the current diagram is drawn so that a good view is had of the manner in which the current and voltage vectors change position with change in load. It is seen how the quadrature currents from the synchronous condenser subtract from or add to the everpresent charging current. At $O\,l$ the quadrature condenser subtracts from the charging current at maximum; then as the load comes on gradually it becomes less until at p the condenser is idling, after which, upon further increase in load, the quadrature current reverses and adds itself to the charging current.

The charging current is shown as a chord of an arc of a circle, more proper perhaps is the circle itself a true representation of the charging current. By a simple geometrical construction, which is obvious, the center of the circle can be found, when it is remembered that except for losses the charging current is in quadrature with the voltage at any point of the line. It is therefor also in quadrature with the voltage at the ends of the line, and hence at right angles to the voltage vectors of the receiver and generator at the various loads.

The arc $l\,n\,p$, etc. is struck from a center m found by locating angle B and making $m\,n$ equal to $o\,b$.

It may, under circumstances, be of advantage to have a drop or a rise in voltage over any particular section of a long line, controlled by condensers at intervals. In such event the diagram at once gives information of what takes place. There may then be a shift to the 110 per cent arc or the 90 per cent arc, or to a curve which would coincide with the 100 per cent arc at no load and with the 110 per cent arc at full load, or vice versa. This is accomplished by adjustment of the potential to the voltage regulator.

The charging current is a function of the impressed voltage. If the voltage is not uniform but changes along the line, the charging current per unit length of line also changes. For a constant voltage system the charging current is therefore constant per unit length of line, and no error is introduced by so considering it.

Ivar Herlitz: The question, so often raised among engineers, whether the hyperbolic theory or some other theory should be used in the calculation of transmission lines seems to me to be rather meaningless. It is established beyond question that the constants in the equations for a uniform transmission line are expressed by hyperbolic functions of certain complex quantities; other expressions for these constants are approximations of the hyperbolic expressions, and it is an easy matter to estimate, for lines of different length, the accuracy obtainable with the various approximate expressions, and then from the demands of the problem decide what method to use. The constants for more general cases, where the transformers are considered together with the line, can be calculated according to Mr. Dwight's paper, or by a similar method described by me in a paper to be published.

The treatment of the equations, after the constants have been determined, depends upon the nature of the problem to be solved. When it is desired to calculate the complete performance of a given line, a circular diagram, for instance of one of the types described in the papers by Dwight and Holladay, may be drawn. In my paper just mentioned I have presented formulas from which the complete performance can be plotted in the form of a few curves giving the loss in active as well as reactive power, and voltage drop for any load condition. For certain other problems I have with advantage used a diagram based on the following principles.

Redrawing Fig. 1 of Mr. Holladay's paper so that the line $O'A$ becomes standard phase, the diagram shown in Fig. 3 is

obtained. Here $O'A$ is proportional to the active power, AP to the reactive power. The circle PP' is the locus for P for fixed values of the voltages. The center of the circle always lies on the line OO', forming an angle with $O'A$ that is constant for a given line. Its position on this line depends on the voltages, and the radius is equal to the sending end voltage. If, however, the values of all vectors in the diagram are divided by V_s, the radius of the circle becomes constant = 1, and if the circle is drawn on a separate sheet of transparent paper it may, by means of scales properly arranged, easily be located with respect to a system of coordinate axes to represent any desired case for any line. One diagram can be used for all lines, and it can easily be provided

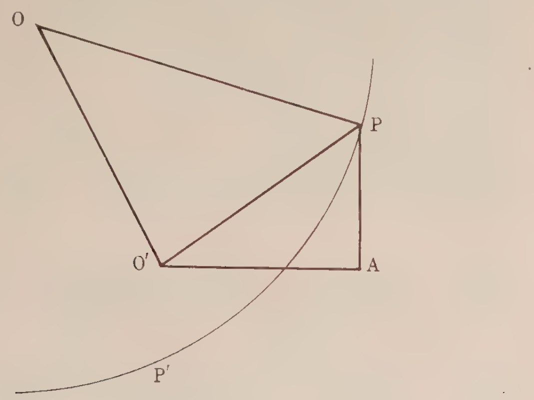

Fig. 3

with scales for convenient determination of all desired quantities. The readings have to be multiplied by certain proportionality factors depending on the constants of the line. A similar circle can be drawn representing the conditions at the sending end, and corresponding points on the two circles are found by means of the angular displacement between the voltages, which is equal to the angle $O'OP$ plus a certain fixed angle, as can be seen from Fig. 1 of Mr. Holladay's paper.

D. I. Cone: I want to call your attention to the comparison of these two diagrams, one in Mr. Dwight's paper, and the other in Mr. Holladay's paper. You get a pretty full diagram presented by Mr. Holladay and the corresponding one discussed by Mr. Barfoed is the physical picture given, which is more powerfully expressive than when you get away from the physical picture, as it seems to me Mr. Dwight is doing on the diagram itself. That is all right for a man who is continually dealing with the problem but for others the whole picture is wanted.

A word about when to use these approximations. In my own work I am sometimes dealing with 50 cycles, and again with 500 cycles or 26,000 cycles, and I have found that it was very helpful to consider what fraction of a wave length of line they are dealing with, and on open-wire lines the velocity of transmission always works out pretty close to 180,000 miles per second. If you have a 60-cycle line, you have 3000 miles for one wave length, and if you are working on a line 150 miles long, that is one twentieth of a wave line—pretty short; but if you set it now to 600 cycles, the line 150 miles long, it becomes half a wave length, which is a very different proposition. In dealing with short lines (I think we can safely define the short line as on the order of one-twentieth of a wave length) we can feel safe in using the approximation. If your line approaches anything at all to a quarter of a wave length, watch out. You had better then recognize the fact that at this time due to the work of Dr. Kennelly and others the hyperbolic functions are practically as easy to use as any of these approximations.

About the effect of irregularities in the line, a recent interesting case came up in connection with the Portland-San Francisco telephone lines being adapted to the carrier transmission between five and 3000 cycles. A quite serious irregularity was found in the voltage current relations on the Portland end. It was found to be due simply to the fact that the spacing was 30 inches between the wires in the City of Portland instead of 18 inches, as on the rest of the line, due to the municipal requirements for climbing spaces. It made a serious irregularity in the sending end of the voltage-current relation which has to be corrected by special means.

F. G. Baum: (by letter): In a paper giving "Some Constants for Transmission Lines" before the A. I. E. E. in 1900 (See pp. 412-422, Trans. May 18, 1900), I showed a method of calculating transmission lines using complex quantities, which showed for the first time the conditions for any load and any power factor. The error for the loaded and unloaded line was shown to be very small for lines less than 200 miles long. And the only error results from the assumption that the charging current is uniform for each line section.

Now, it is admitted that to transmit power over very long distances we must have synchronous condensers at certain intervals to maintain a *constant voltage system* as shown in my paper on "Voltage Regulation and Insulation for Large-Power Long-Distance Transmission Systems." A. I. E. E., 1921. If we do this then it follows that the charging current is also a constant. And if the charging current is uniform, then there is no need for the hyperbolic calculations.

If we are not to hold the line voltage constant, then I admit we need the hyperbolic method of calculations. But why use a method of calculation for an impractical system?

Diagrams 2 and 3 of my paper referred to are *absolutely* accurate. Diagram 4 is accurate enough for all practical purposes. Diagram 5 was given to show the general problem visually. An error in making the diagram accounts for the discrepancy pointed out by Mr. H. B. Dwight and which I acknowledged to him.

In my method we calculate not a 500 or 1000-mile line but calculate the sections between condensers. The errors resulting could never be measured on the completed line by any instrument used in operating the system. The results are shown visually for all conditions of loading.

H. L. Melvin: We who are actively engaged in transmission line design have our pet way of making calculations, I am sure. Whether we use a simple calculation, a graphical chart or an exact solution, depends entirely upon the problem, and it is really our own good judgment which tells us just which solution to use. Furthermore, I believe most of us know how to use any of the methods which have been devised by the technicians. These methods which we have are really a combination of our own study originality and the ideas of others. Personally I like to use the Perrine-Baum graphical chart simply because it gives you a very nice picture of the actual performance of the transmission line. I simply take a piece of cross-section paper and determine upon the kilowatt scales, use one wire values and make a chart somewhat similar to that devised by Professor Carpenter and presented, I believe, at Los Angeles in 1919. It is a Perrine-Baum chart modified, from which you can get practically all the information you want, voltages, per cent voltage regulation, kilowatts, kilowatt-amperes, power factor and synchronous condenser capacity for power factor correction. On the kv-a. circles the I^2R transmission line loss can be placed. The point where the loss in the synchronous condenser increases faster than the I^2R loss in the line decreases can also be determined. That point is approximately the economic or most efficient point at which to operate the transmission line. If you have a problem which requires a more exact solution, the values of resistance and reactance can be modified by the use of hyperbolic functions, and what Dr. Kennelly calls the equivalent values, derived. These values can then be used for making the chart. If you have a still more complicated problem, go through the exact solution. In any event I would make a chart to give a picture of the line, so that good judgment can be used in the design.

Pictures mean a great deal to me, if I can see before me just exactly what is going on, I feel that I am better prepared to use good judgment in the proper design. The accuracies of calculation usually exceed by far the original assumptions and necessity in practical application. Temperature change in an ordinary transmission line will introduce more error than the difference between the exact and approximate solution.

Do not misunderstand me, I am not attempting to minimize theory and exact solutions. I have been through them and I feel that I understand them, and they certainly have their value, and unless you do know them you do not know when you can use an approximate solution, or when you have to use an exact solution. The exact solutions are of course absolutely essential on the larger problems. Some of the papers which have come out in recent years are more or less duplicates of papers that have preceded them. I have in mind the sag tension proposition. There were papers after papers on sag tension, different methods of calculation and so on—exact methods and approximate methods. The exact method might tell you to put seven and one-tenth foot sag in the conductor, the approximate solution might say seven feet. If the lineman, gets it within ten per cent, you are lucky.

If you study or go back through the papers that have been written on transmission line regulation and the sag tension problems you will find about every five or six years some one has practically copied an idea of some one before him. We should be careful to give due credit when that is done.

Again I say, practically every one of us have our own pet schemes and could possibly devise some originally and perhaps claim something special for our way of calculating. All these papers are of value if we study them. What we know and use, really are a combination of the other fellow's ideas, coupled with our own.

H. B. Dwight: It has come to be a rule followed by a good many engineers that, in calculating a transmission line at commercial frequencies, if the charging current or capacitance is worth while considering at all, it is worth while calculating its effect by the hyperbolic method. For instance, the old split-condenser method gives rise to an unknown amount of error, and it is better to remove the uncertainty and at the same time effect a standardization of method of calculation, by using the hyperbolic method, which takes practically the same amount of labor as the other.

When a method is advocated which is explicitly not based on the hyperbolic method, it is not sufficient to examine whether its theory appears accurate or nearly accurate, but it is necessary to use the proposed method with a definite example and see if it gives correct results. For this, the criterion by which it must be judged is the hyperbolic method.

Thus, in the last paragraph of Mr. Barfoed's discussion it is stated that "in a constant voltage system the charging current is constant per unit length of line, and no error is introduced by so considering it," but he does not mention any problem which he has worked out as a check of the correctness of his theory for practical purposes, and therefore his statement remains open to doubt until he puts it to the test in the manner described.

So also, referring to the same or a similar method of treating charging current, F. G. Baum says in his discussion that in a constant voltage system the charging current is a constant, "and if the charging current is uniform, then there is no need for the hyperbolic calculations." Now the charging current may be roughly uniform, but the only way to test the above statement is by its results.

Mr. Baum states that the large errors which I pointed out in diagram 5 of his 1921 paper are due to an error in making the diagram, but he does not say, as one might reasonably expect, that he had re-drawn the diagram and found what the errors due to his method really are.

However, he states that "diagram 4 of the same paper is accurate enough for all practical purposes." Now diagram 4 gives complete electrical data of a transmission line of two sections, each 150 miles long, and it is possible to check the results, which are as follows:

RATING OF SYNCHRONOUS CONDENSERS

Synchronous condenser station	Baum's Method	Hyperbolic Method
$S\ C_3$	9,000 kv-a.	22,600 kv-a.
$S\ C_2$	18,000 kv-a.	17,190 kv-a.

If an engineer built a synchronous condenser station for 9000 kv-a. and it was found after load was put on that 22,600 kv-a. of condensers were really required, he would have difficulty in convincing his superiors that his calculations were accurate enough for all practical purposes.

If a method of calculation different from the hyperbolic method is put forward, the advocate of the method should himself first, give clear instructions for using it; second, use it to solve a practical problem; and third, solve the same problem by correct standard methods and show a comparison between his results and the correct results.

A Piezo-Electric Method for the Instantaneous Measurement of High Pressures

Quartz plates properly cut from quartz crystal liberate an electric charge when subjected to pressure. A stack of these plates are placed in a small steel container in the form of a plug which is screwed into the breach block of a gun.

The charge which is liberated when the gun is fired passes through a special type of galvanometer and the galvanometer movements are photographed on a rapidly moving film. By means of the trace on the film it is possible to determine the pressure at any time during the explosion, also the rate of combustion of the powder, the velocity the projectile would have if there were no friction, etc.

The device can also be used for measuring the impact or "force of blow" struck by hammers, baseballs, boxing experts, rifle bullets, automobile bumpers, clock and watch escapements, etc.

This method of pressure measurement is described in a forthcoming Scientific Paper No. 445 of the Bureau of Standards.

Electrical Safety Code

A committee consisting of over 50 representatives of state utility commissions, national utility associations, insurance companies, electrical manufacturers, electrical workers, and others interested in the subject of safe construction and operation of electrical supply and signal lines has been organized to cooperate with the Bureau of Standards in the revision of Part 2 of the National Electrical Safety Code, which deals with this subject.

The first meeting of this committee was held at the Bureau of Standards on November 2 and arrangements were made to carry out whatever revision of the overhead line rules may appear to be desirable for a new edition of these rules. This portion of the Electrical Safety Code is now recognized generally as a standard. It has been adopted by a number of the state utility commissions and has been approved as an American Standard by the American Engineering Standards Committee. Detailed specifications for the various situations in which wire crossings are involved will be drawn up in conformity with the requirements of the National Electrical Safety Code.

The Relation of Overload to the Inner Temperature of Machines*

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OVERLOAD is generally regarded by users of electrical machinery as a convenience. Very few consider the meaning of a rating containing overload allowances (double rating) from the point of view of the comparability of different makes of machines and of the effects that overload allowances may have on the duration of the insulation of the machine. The object of this paper is to show, in an elementary way, the process of heating going on in electrical machines and to consider what is the fundamental difference between single rating (no overload allowed) and double rating (overloads allowed) and to supply a clear and sound basis for an eventual discussion. I shall here only refer to continuous rating and the word machine will indicate generators, motors, converters and transformers cooled by natural ventilation.

If we want to design a model of an electrical machine in order to follow its thermic behavior, we can imagine it as drawn in Fig. 1. M is a mass of iron thermically insulated by a coating K, and leaving open in contact with the air, the surface $a\,b$, the diffusing surface. A is a conductor. I the insulation. We shall neglect the representation of the heat produced in the iron, as this does not change the results of this study. In the conductor A a certain quantity C of heat is produced per unit of time and is transmitted across the insulation

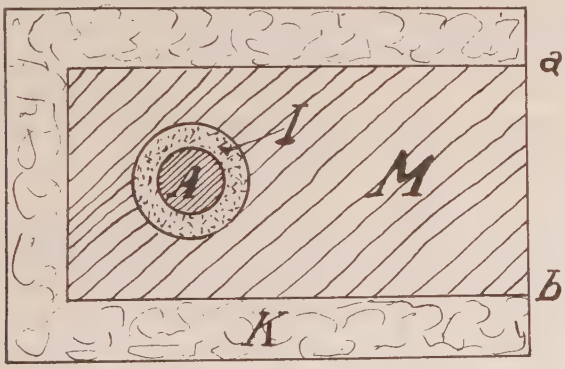

FIG. 1

and the iron mass M to the diffusing surface from which it passes by convection and radiation to the cooling air. If we suppose the temperature t_0 of the cooling air to be constant after a certain lapse of time we shall reach a condition of equilibrium in which all the heat produced in A in a second is transmitted to the air in the same time and therefore all the points of the machine will have reached a steady temperature. In such a condtion if we measure these temperatures we shall be able to plot them in a diagram, more or less, of the appearance of the one shown in Fig. 2. The temperature t_1 of the conductor or heat generator falls across the insulation to t_2, the fall being ruled by a law similar to Ohm's law; the fall of temperature in fact is directly proportional to the flow of heat and to the inverse of the thermal conductivity of the mean. A second fall of temperature occurs in the mass M to t_3 the diffusing surface temperature, and a third on $t_3 - t_0$ the fall occurring between the surface and the mass of the cooling air. The effect of heat generated in the iron

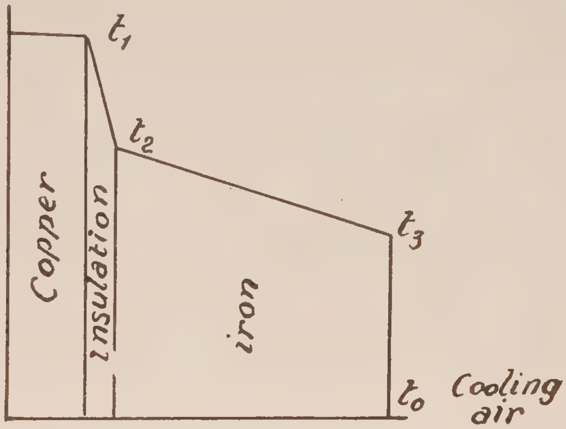

FIG. 2

mass will be to increase the inclination of the line $t_2\,t_3$. As we have means of measuring t_1 and t_0 and the current in A, we can, in these steady conditions, know exactly what is going on in the machine. If we assume t_0 to be the maximum cooling air temperature, we can at any time in the life of the machine be sure that the temperature of the copper, hence of the insulation in contact with it, will never rise above the value t_1, provided that the current in A does not increase over the rated intensity.

We can easily realize also that with the same production of heat (that is, losses in the machine) even with very large difference in the thickness of insulation and of the mass of iron we can keep the temperature t_1 of the conductor below a certain allowed maximum, by adapting the area $a\,b$ of the diffusing surface to the conditions of the special case. A thick insulation (high-tension machine) will give a greater fall $t_1 - t_2$ in the insulation than a thin one (low-tension machine) therefore in order to have t_1 constant, the value of t_3, that is the surface temperature of the machine, will have to be lower in the case of thick insulation, which can only be attained by increasing the diffusing surface. The same may be said for any condition which will increase the internal thermic drop of the machine.

*Presented at the Niagara Falls Convention, June, 1922.

Therefore machines of different tension, speed, construction and make can be so designed, that in the steady normal conditions, or in other words, at their rated power, the temperature of the conductors, hence of the insulation, shall never exceed the prescribed value.

Going back to our model let us suppose that a certain steady thermal condition is reached and let us increase by a certain per cent the current in the conductor, so that the production of heat per unit of time would be increased from C_1 to C_2. At the first instant after the increase the thermal flow is still determined by the pre-existing conditions, so that the quantity C_1 of heat is transmitted through the insulation under a difference of temperature $t_1 - t_2$. As in these conditions not more than C_1 can leave the conductor, the extra heat $C_2 - C_1$ is stored up in the conductor raising its temperature from t_1 to t_1'. This allows an increase of flow of heat across the insulation. But if we suppose the

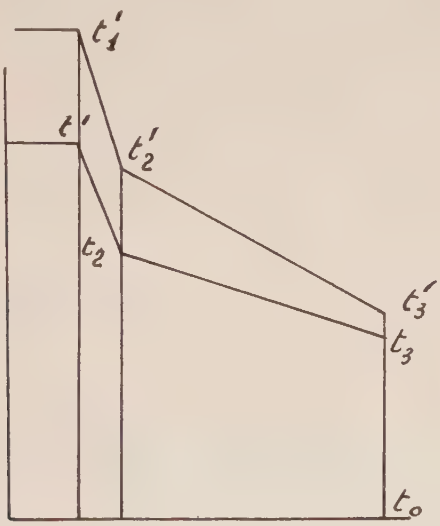

Fig. 3

insulation is formed by a superposition of very thin layers, each of them, receiving more heat, stores up a part of it in order to increase its temperature before it can increase its transmission to the following layer, and so on. Considering the whole path through which heat is transmitted (insulation and iron) we can say that in the variable period following an increase in the quantity produced, each element in a first period stores up heat then transmits it to the following one, and this process goes on till a new steady condition is reached in which in every unit of time an equal quantity of heat is produced and diffused in the air. For this condition we shall be able to plot a new diagram. Now what it is of interest to know is the new value of t_1 and the time the system takes to reach it. The knowledge of both these elements is necessary. When overloads are stated for a limited period of time it is important not only to know what is the maximum temperature reached, but also if during such period the new steady temperature is reached.

Many causes may influence the behavior of the machine in this variable period.

First, the thickness and nature of the insulation, or in other words the thermal conductivity of the whole layer of insulation, as upon this will depend the fall of temperature and the length of the variable period.

Then comes the construction of coils. As to transmission of heat, a single bar conductor is something very different from a coil of very thin wire with heavy insulation. Thoroughly impregnated coils are in this respect different from coils merely coated with shellac or varnishes.

The magnitude of the iron mass and its laminated construction with respect to the direction of the flow of heat, have a good deal of importance, and here especially we meet with differences in the storing effect and in the fall of temperature necessary to drive the heat across the mass itself.

Where the heat produced comes to the diffusing surface the temperature of the surface has an influence on the quantity of heat diffused by convection and by radiation; the diffusing coefficient is not constant, but increases with temperature and with the difference of temperature between the surface and the air. This phenomenon, which is from a certain point of view beneficial, is different in different machines.

In conclusion machines of different tension, speed and construction, which at their steady normal conditions of work reach the same rise of temperature in the copper, when overloaded say for one hour with the same percentage of overload, necessarily reach different temperatures in the copper as all the elements by which they differ (insulation thickness, revolutions, power, storing capacity, dispersing surface) have different effects on the rise of temperature. Moreover in some machines the end of the overload period will find the new steady conditions established, in others, especially in heavy machines, this state will not have been reached.

So we may summarize by saying that machines quite comparable at their normal rating for continuous service are not comparable the same percentage of overload imposed for the same period of time.

All forms of rating with overloads (double ratings) in use or proposed up to the present are intended to apply to a large variety of machines, and contain only rough divisions in two or a few classes according to power. If the German rules are excluded (in which it was not question of thermal overload) no mention is made of temperature. The buyer must be satisfied with the seller's declaration that overloads will not spoil the machine.

The aim of an international rating rationally considered is to provide a manner of defining what a machine really is. The buyer must be able to compare offers of machines of different makes and countries by their ratings.

With the single rating he can do it quite well; he

knows that a machine rated at 10 kw. will give him 10 kw. in a continuous manner without submitting the insulation to dangerous temperatures. If he wants to overload his machine it is at his own risk. All this is clear, plain and simple.

When a double rating is given in the ordinary forms without stating the final temperature what does the buyer know about his machine? He knows that at the rated power for continuous run, the insulation of the machines will not have to bear a temperature higher than a certain specified value, but how can he compare offers if, as we have seen, the different machines under overload all have different behaviors as to the rise of temperature? How can the buyer be sure of the duration of his machine knowing that high temperatures are dangerous if applied for a certain time, and not knowing anything of the value of such temperatures and of the length of time they are applied?

One conclusion is that the rating of machines for continuous service, without any allowance for overloads (single rating) is a definite and clear specification and constitutes a fair basis for commercial transactions.

A rating given for continuous service but allowing overloads (double rating) could only be compared to the single rating provided it can be demonstrated that the same overload applied to machines of all sizes, tensions, speeds and construction bring practically to the same ultimate temperature and to the same fatigue of the insulation.

That such a demonstration can be given in the actual conditions of the industry is a matter of discussion.

Should the answer be negative then the only solution, when double rating is wanted is to call for the specification of the temperature reached after the allowed period of rated overload.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

NEW YORK STATE BOOSTS HIGHWAY LIGHTING

A bill has recently been passed by New York State which allows the counties of the State to appropriate money for the illumination of highways. This bill is an important and logical step toward providing means of financing highway illumination, placing authority in the hands of the board of supervisors of any county to provide for lighting public highways, or portions thereof, or bridges, located in such county outside of cities and villages. The board must submit proposals to the State Commissioner of Highways when it is desired to provide lighting for some highway or bridge. The Commissioner either approves the proposals or suggests such modification as he sees fit, returning them to the board for final adoption. The expenses for installing and maintaining the lighting system is provided and appropriated in the same manner as other county expenses.

The importance of highway lighting is becoming more seriously recognized in all parts of the country and the passage of the above mentioned bill will prove a big help in the rapid development of New York's highways to meet the requirements of modern traffic. Other states will doubtless consider the inauguration of similar legislation.

ELECTRIC SIGN STATISTICS

Probably no organization connected with the electric sign and outdoor display lighting industry has ever undertaken the gathering of statistics on electric signs. Authoritative information as to the number size, cost, value, design and effectiveness of electric signs, the growth of the industry, or the distribution among the various classes of advertisers has not been available. In a vague way, sign men agree that this city has good signs, that one poor; that a general class of advertisers has found electric signs effective and that others do not use them, etc. Each of the larger sign companies has on file records of its own business, but even if this information were consolidated, the data obtained would doubtless be very incomplete.

The following data obtained through a preliminary questionnaire sent to electric sign manufacturers may be of interest:

City	Population in thousands	Number of signs	Value in thousands of dollars	Persons per sign	Value per sign dollars	Total in thousands	Sockets Per sign	Sockets Persons per socket
1	160	105	29.5	1524	281	5.4	51.5	29.60
2	10	18	5.4	555	300	2.0	111.0	5.00
3	45	480	150.0	94	312	15.0	31.3	3.00
4	325	900	720.0	361	800	135.0	150.0	2.40
5	350	58	180.0	583	300	240.0	400.0	1.46
6	18	10	23.0	310	396	3.0	51.8	6.00
7	20	750	4.0	2000	400	2.0	200.0	10.00
8	340		300.0	453	400	187.0	250.0	1.80
Total	1268	2921	1411.9			589.9		
Average				735	398		202.0	2.15

Any conclusions drawn from such a small part of the whole country, are, of course, liable to question. It is very significant, however, that practise actually does vary as widely as is shown. There may be something in the nature of the cities, their people, or their industries to explain why in one case there is a sign socket for less than two persons and in another, one for each thirty, only. Also there may be some logical reason for the wide variation in the average size of signs in different cities. But is it not much more probable that central station and sign promoters have been more active in one city than they have been in the other?

The Physical Nature of the Electrical Breakdown of Solid Dielectrics*

BY KARL WILLY WAGNER

Telegraphen-Technisches Reichsant, Berlin

WHILE the physical phenomena in connection with the electrical rupture of gaseous insulators have been thoroughly investigated by J. J. Thomson, J. Stark, J. Townsend, J. B. Whitehead, F. W. Peek, Jr., and many others, the nature of the breakdown in solid and liquid insulating materials has up till now remained in complete obscurity.

According to the prevailing opinion the rupture takes place at the moment when the density of the electrical field exceeds a certain limit at any point in the insulator. This is called the electrical strength of the material and is based on a reasoning analogous to that which gave rise to the theory of mechanical resistance against a breakdown.

However, there are recorded observations about the rupture of insulating materials which one is unable to reconcile with the general opinion that the rupture takes place as soon as the electric field strength exceeds the critical point. I made such an observation during the year 1905, and as it made me at that time doubt the correctness of the existing theories I shall endeavor to discuss it here.

Fig. 1 shows the cross-section of a concentric cable. A number of these cables, with various ratios of R to r, that is the ratio of the outside diameter of the insulation to the inside diameter, were measured for breakdown voltage. From this the maximum field density E,

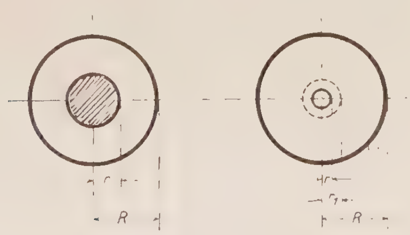

FIG. 1

existing along the radius r was calculated. The result was that as long as the ratio $R:r$ did not exceed a certain limit, approximately 2, the maximum field density was equal to that which existed when rupture took place on flat plates of the same material, namely E = 10,000 volts per mm. For large values of R to r, however, the rupture took place after E had increased to about 15,000 volts per mm.

Some one immediately suggested as an explanation that the inner layers of the insulation had been ruptured after E had exceeded 10,000 volts, and that as a result the diameter of the conductor had in effect increased from r to r_1, with a consequent decrease in the maximum field density even while the tension remains the same.[1]

In order to test this assumption a cable-section was subjected a certain length of time to a tension nearly reaching the limit, so that at least the inner part of the insulation from r to r_1, was subjected during this period to a field density far in excess of the rupture limit. Then the paper insulation was unwound till the supposedly ruptured part from r to r_1 was reached. What remained of the cable section was then provided with a metal cylinder, and subjected to an electrical tension. The test showed it to be perfectly intact and it ruptured only at the normal limit, (10,000 volts per mm.). It was thereby proved that such a material can be subjected without disadvantage to an electrical field density far above the normal.[2] This one and other tests show, therefore, that the analogy generally assumed between electrical and mechanical strength does not exist. Moreover I dare claim that this assumed analogy has not in the least promoted a clear understanding of the electrical phenomena; on the contrary it has been an obstacle in the way of understanding the true nature of things.

I observed during the numerous rupture tests which I conducted some years previously that the material prior to rupture heated up considerably in some places, while other parts remained comparatively cool, and that the rupture always took place at such a spot after it had become hot. If the current is interrupted before the rupture has taken place, and the heated spot is examined after cooling down, it is found that the electrical qualities of this spot do not differ materially from the spots which remained cooler.

Why then does the rupture occur at the heated spot?

It is a well known fact that the resistance of the insulation decreases rapidly with increasing temperature. The hot spots therefore take up a larger current than the adjoining cooler spots, which are subjected to the same tension. It is evident that the hot places receive more energy than the cooler ones, with the result that the temperature difference further increases. It is easy from this to picture that at a certain tension an

*Presented at the A. I. E. E. Spring Convention, Chicago, Ill., April 20, 1922.

1. Similar experiments were undertaken later by M. Klein, E. T. Z. 1913 p, 851.

2. A. Russel, in a paper in the JOURNAL of the I. E. E., Vol. 40, 1907, p. 6 has developed a theory based upon the same assumption.

unbalanced condition takes place, and the hottest spot finally burns.

This is my theory of the physical occurrences at electrical ruptures of solid insulators.

It could be said that although this analysis is apparently simple, at first it seemed difficult to draw comprehensive conclusions as to the occurrence of ruptures depending on various factors. However, this did prove possible, and I will show in the appendix how by making certain simple assumptions this proved to be the case.

For the present time I wish to point out only the general lines of the theory and the most important

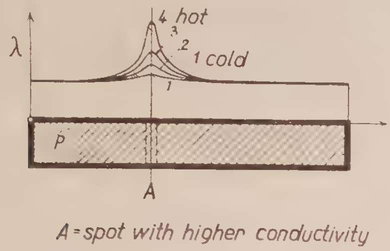

FIG. 2

conclusions drawn from it, and at the same time to show in just what manner I have endeavored to disclose the nature of the rupture phenomena by experiment. The work is not as yet concluded, but the data already obtained are sufficient to support the conception represented in this paper.

Take a plate P of insulating material (Fig. 2) provided on both sides with electrodes. This plate will not possess the same electric conductivity all through its section, but on the contrary, due to the lack of homgeneity in the material the conductivity will be higher in some places than others. Let A be such a place.

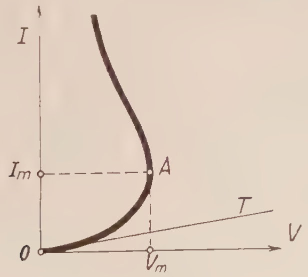

FIG. 3

Curve 1 may represent the original distribution of conductivity in the plate section. Subject the plate now to a certain potential, and a current will traverse the plate. The current density will be a little higher in A than elsewhere. The insulating plate is heated by the current, and to a larger degree in A than elsewhere. Now as the conductivity increases directly with increasing temperature, the conductivity distribution of the plate under electrical tension, will be represented by curve 2. Note the increase at A over curve 1. If, at the increased temperature at A, the heat conducted to the surroundings of A is equal to the heat created in A, curve 2 will remain stable. If the opposite is true, then the curve will become still more pointed. This also may happen, (curve 2 representing a stable distribution) if the electrical tension V is increased (curve 3). Finally a condition occurs represented by curve 4, during which the created heat grows faster than the heat conducted to cooler parts, and the temperature grows more and more rapidly and similarly the conductivity, and the current, until the rupture takes place at A.

The above leads to consideration of a thin thread of the insulating material.

The initial resistance of the thread may be R. As long as the voltage V remains small, the heating according to Joules law remains small and the resistance constant.

The current voltage characteristics (Fig. 3) are thus a straight line $O\ T$. With increasing tension the thread heats up and the resistance decreases, consequently the current increases more rapidly in proportion to the tension. Finally a point will be reached when the resistance decreases further, without a corresponding increase in the voltage. This is the rupture point and the voltage V_m, is the breakdown voltage.

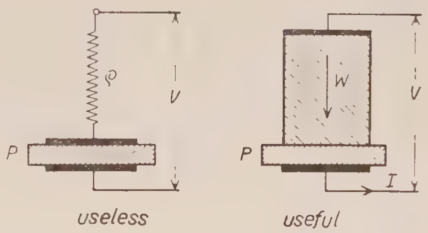

FIG. 4

It is easy to determine by experiment the characteristics up to point A. The portion above A represents the unstable condition, and this is passed at an immense speed and can therefore not be observed.

After I had made the above analysis, I was, of course, tempted to make an experimental test. At first I could see no possible way of determining the portion of the curve above A. Other work took up my time and interest and it was not until I began investigations on the nature of dielectric losses and their laws, that my attention was again directed to the rupture problem. In 1914 when these investigations were concluded[3] I found time to experiment again with the rupture phenomena.

I had previously tried to disclose the characteristics of the curve above A by means of connecting a high

3. The theory of imperfect dielectrics, "Annalen der Physik. Vol. 40, 1913, p. 817. "Dielectric Viscosity," *Elektrotechn. Zeitschr.* 1913, p. 1279. "Explanation of the Dielectric After-Effect according to "Maxwell's Theory," *Archiv. f. Elektrotechnik*, Vol. 2, 1914, p. 371. Dielectric properties of some insulating materials," *Archiv. f. Elektrotechnik*, Vol. 3, 1914, p. 67.

resistance in circuit with the plate of insulating material (Fig. 4, at the left.)

I hoped that this resistance would perform in a manner similar to the stabilizing resistances of electric arcs, and thus allow an observation of the points of the curve above A. This, however, proved futile.

Even when using very high resistances and corresponding high tensions V_o, it was impossible to reach beyond point A. Always a complete rupture took place, as soon as A was reached.

The following explanation was found for this unexpected result:

The insulating body with its two metal electrodes forms a small plate condenser.

At point A, where the insulating material begins to give way, an amount of energy $1/2\ CV_m^2$ is stored in this condenser, C being the capacity of the condenser. This stored energy jumps at once at the weak spot and feeds during a short time a much stronger current than the ordinary source of current, could supply over the resistance.

In other words the energy required for rupture *i. e.*, local burning, is supplied by the electrical field energy of the condenser. I found the following way out of this difficulty.

The resistance should form part of the electrode itself, *i. e.*, make the latter of poorly conducting material. The best material would be such as to lead the current only in one direction through the electrode that is in the direction of the arrow (Fig. 4, at the right). With such an electrode each thread of the material would be fed with current independently of all others through a constant resistance.

The current supply of a weak thread, could not come from adjoining parts, as occurs with metallic electrodes just before rupture.

The material which, most nearly meets the desired specification, is wood although it is not quite perfect.

Its conductivity across the grain is not zero, but it is considerably smaller than in the direction of the grain.

By means of impregnation and the choice of suitable kinds of wood the required range of resistances can be procured.

Thus, in the beginning of 1914, it was possible, after overcoming several experimental difficulties, to plot curves for the rupture characteristics of different kinds of paper, gutta percha and rubber. They showed the expected form of Fig. 3. Unfortunately the experiments had to be discontinued when the war broke out and could not be resumed until 1919. Since then I have been graciously assisted by Messrs. Stahl, Kupfmuller, Mitzel, Dr. Dieterle and Ludwig in carrying out the experimental work.

The method of recording the characteristics was as follows:

The $V I$ curves were taken with the arrangement shown in (Fig. 4, at the right) both with the wood electrode alone and with plate P inserted.

The difference of the tensions read for the same current in both cases is the tension of the insulating plate P belonging to this current.

As source of current we used partly a rectifier fed with 500 cycles alternating current, and partly an electrostatic induction machine.

In order to avoid using too high tensions, V, the insulating material was tested in the form of thin plates (in some cases down to a few hundredths of a millimeter). The tests covered so far include different kinds of paper,

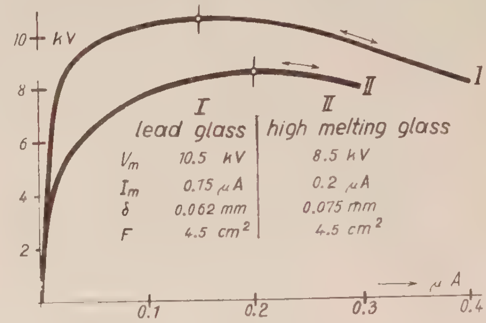

FIG. 5

oiled paper, paraffined paper, gutta percha, vulcanized rubber, cellon and similar materials, glass and mica.

Due to lack of space, I can give only a short report of the tests. Therefore, I shall confine myself to a description of the most important results in general.

In Fig. 5 there are represented the breakdown characteristics of two different kinds of glass (lead glass and high-melting glass). Fig. 6 shows the characteristic of mica; Fig. 7, those of cellon (two plates of different thickness); Fig. 8, that of another product manufactured from

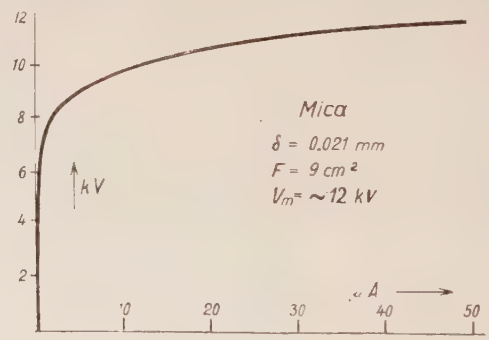

FIG. 6

cellulose. In the latter case, the wooden electrode had been covered with tinfoil. This experiment therefore relates to an arrangement as represented at the left of Fig. 4. According to the remarks formerly made, we observe the current suddenly increasing as soon as the breakdown voltage V_m is reached, while the tension diminishes to a small fraction. A hole burnt into the sample was found by inspection after the experiment.

The following statement has been proved to be of general validity:

The rupture voltage is in direct proportion to the thick-

ness of the tested material and independent of the size of the plate.

As an example, the data from a series of tests with gutta percha are shown in Fig. 9.

Of course, the particular characteristics of different samples of the same material do not coincide exactly due to the lack of homogeneity of any dielectric, and therefore the preceding statement relates to the mean voltage obtained from a number of equal tests.

When testing for ruptures with the usual metallic electrodes, the rupture voltage, as we know, grows

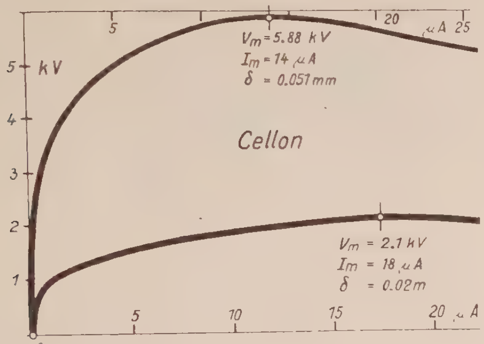

Fig. 7

slower than proportional to the thickness of the plates. This results from the distortion of the dielectric field on the edges of the plates. On the other hand with the method herein described the edge effect has very little influence, because the current flowing at the edges is only a very small portion of the total current, plotted in the characteristic curve.

If the characteristic curve of a transparent material is carried on to currents beyond the rupture point, and the material is inspected under a magnifying glass or a microscope, it is often found disturbed at a large number

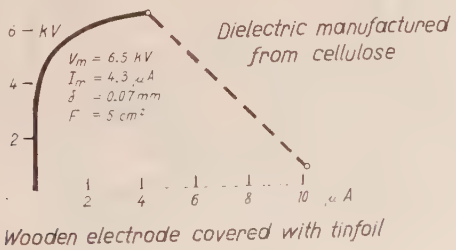

Fig. 8

of points and rendered dull. The characteristic obtained is therefore, the *mean* characteristic of all these "spoiled" paths. It may be understood that the material at these places has been spoiled by excessive current. When decreasing the tension from point B downward (Fig. 10, at the left), the curve 2 is obtained. This curve however, contains also the current of those paths, which were heated only and thus made better conductors, but not burnt.

By waiting until the material has cooled off, and then again taking the characteristics, curve 3 is obtained. On the other hand if the characteristic is taken for the first time up to a point B, below the maximum, and then down again, the two characteristics practically come together. (Fig. 10, at the right). The fact that they do not cover each other entirely, demonstrates that several particularly bad spots had already undergone damage during the rising curve.

The characteristic shown in Fig. 11, relating to a thin sheet of vulcanized rubber may be taken as an example, representing the case just mentioned.

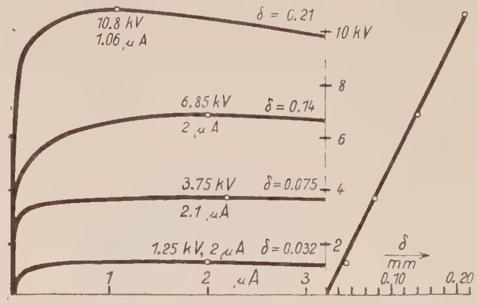

Fig. 9

The hump on the characteristic curve of oiled paper (Fig. 12) is by no means due to an error in the test, but has been regularly observed with numerous tests with the said dielectric if the whole of the characteristic curve was passed in a short time. If, on the contrary, the characteristics were taken slowly the regular shape was obtained as represented by the dotted curve in Fig. 12.

With most of the glasses the rising branch of the characteristic does coincide with the descending branch (see Fig. 5). In such cases the characteristic

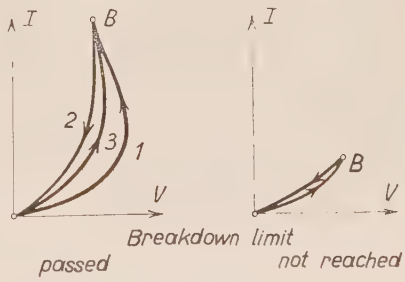

Fig. 10

curve may be passed several times up to points far beyond the rupture point without doing any damage to the dielectric. Part of the glass plates cracked when some point of the curve beyond the breakdown voltage was reached; that was obviously due to overheating of particular spots of the plates.

As a result of the lack of homogeneity of the material, the rupture voltage determined as usual with *metallic electrodes* is evidently depending on the electrode area. Each rupture test only gives the rupture voltage of the worst spot of the tested sample.

If the same number of tests is made on small and large areas, the chances of finding bad spots in the latter case is greater, and consequently with large areas a lower mean value of rupture tension is arrived at.

Geweeke & Krukowski[4] have proved the correctness of this assertion. They made n times as many tests with small electrodes of area f as with large electrodes of area $n \times f$; then they took from each series of n successive tests with small areas the lowest rupture voltage. The mean value of all these minimum voltages was found equal to the mean value of all the rupture voltages with large areas.

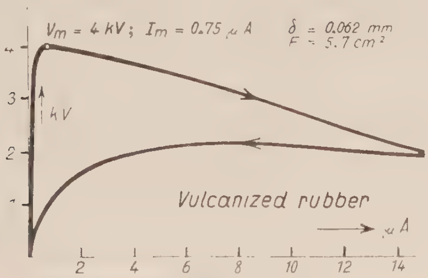

Fig. 11

I repeated these tests together with Mr. Stahl and found the same results. Mr. Stahl worked out a method of calculation, to determine the mean rupture voltage for any larger area from the distribution curve of the rupture voltages with small areas. Mr. Stahl's method is based upon the calculation of probabilities, and his results were also found in conformity with the test results. With the wood electrode test the mean breakdown voltage is determined, and this, of course, is independent of the area of electrodes except perhaps for very small areas.

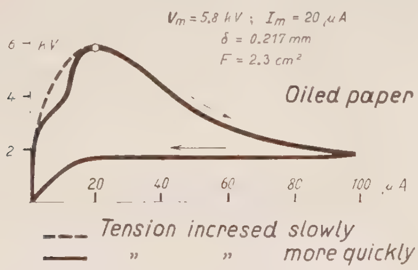

Fig. 12

It appeared desirable to follow through mathematically the thought that an insulating plate is ruptured by the overheating of the material caused by the current flowing through a weak spot. It could be hoped to find in this way certain relations which could be tested experimentally.

I do not wish to take up much of your time by producing here mathematical deductions,[5] but shall briefly give my considerations and the conclusions derived.

If we increase the voltage slowly so that thermic equilibrium is maintained in the material, the electrical energy delivered to one fibre $R I^2$ must equal the amount of heat energy per second conducted from that fibre to the cooler surrounding parts of the material.

If we know the relation of the resistance R of the fibre to the temperature, we are able to calculate the characteristic current-potential curve of the fibre (V = function of I) by means of the mentioned equilibration condition.

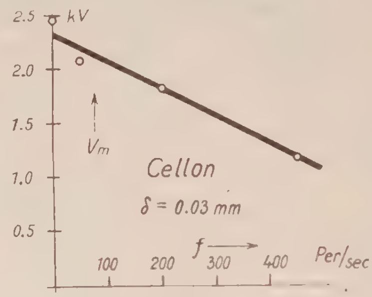

Fig. 13

It is well known that the resistance of insulating material decreases rapidly with increasing temperature, and that we can easily express this relation through some exponential or other function of the temperature.

With these and similar assumptions I have succeeded in calculating the characteristics of a material I. E., to determine the curve by means of the electrical and thermal constants of the material.

It is remarkable that the result of these calculations and the considerations mentioned further on depend very little on the specific assumption which has been made about the decrease of the resistance with increasing temperature. The shape of all these calculated characteristics conforms fairly well with the observed ones; and the theory is proved that the rupture voltage is proportional to the plate thickness.

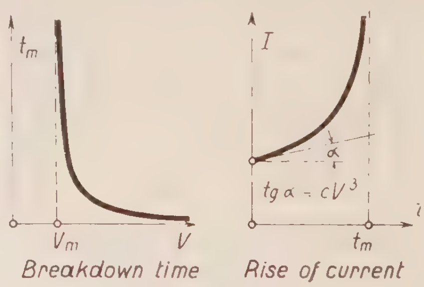

Fig. 14

Insulating material subjected to *alternating voltage* is heated not only by the current, but also by the dielectric losses. These are approximately proportional to the frequency and the square of the tension. If we consider these dielectric losses in the heat equilibrium condition,

4. *Archiv. f. Elektrotechnik*, Vol. 3, 1914, page 63.
5. See the Appendix.

we find that the rupture voltage with alternating current must be smaller than with direct current. With low and medium frequencies it decreases in a linear function of the frequency (Fig. 13). This law was corroborated by our tests, which up to now covered frequencies from 0 to 500 cycles.

Until now, it has been generally assumed that the maximum or peak value of the voltage curve would be responsible for the rupture. According to the overheating and burning theory of rupture, it is the *effective tension* which might be expected to be mainly responsible for the breakdown. There would exist, therefore, a very distinct difference between gaseous and solid dielectrics. This is a highly important conclusion of the theory, and it had to be borne out by test. By elimination of parts of a sine wave, a tension curve with a low effective value but a high peak was generated. The effect of this tension on the insulating material was very approximately proportional to the effective value and the short-lived high peak could be a considerable multiple of the rupture voltage, without causing a rupture.

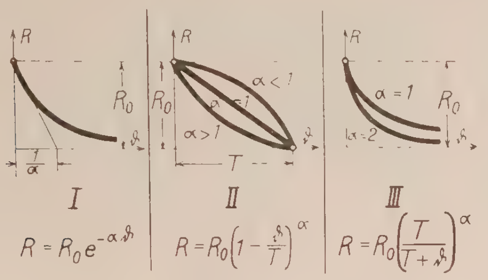

Fig. 15

Following these tests, we made tests with short single shocks, similar to those used by Mr. Peek in testing spark gaps. These shocks were created by a non-periodic condenser-discharge. In this case the effective value of the impulse, $\int_0^\infty V \, d\, t$ apparently governs the effect on the insulating material. These tests, however, are not concluded as yet.

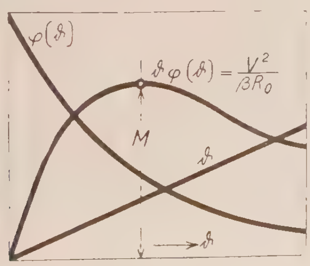

Fig. 16

If the tension exercised on a piece of insulating material is increased rapidly, the breakdown does not occur instantaneously, as soon as the rupture voltage is reached. We can, therefore, subject the material for a short time to a tension V, which exceeds the normal rupture tension without a rupture taking place.

For each voltage V, exceeding the breakdown voltage we find a time t_m, which elapses before the rupture takes place. (Fig. 14, at the left). The retarding of the rupture comes from the fact that with each temperature increase, heat energy has to be stored in the insulating material. This of course requires time.

The theoretical treatment of this problem showed the remarkable fact that the form of the curve (Fig. 14) does not depend on the kind of the tested material, if the scales of time and voltage are properly chosen. This means that the ratio of the heat capacity to the heat conductivity of the material has to be taken as unit of time and the breakdown voltage as the unit of voltage.

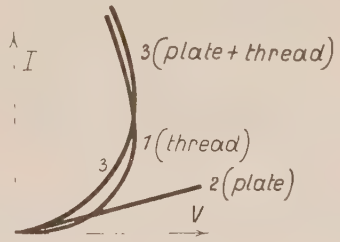

Fig. 17

The current traversing the insulating material increases with the time as shown in Fig. 14, at the right. This is another relation which may be calculated theoretically.

An interesting conclusion of such calculation is that the increase of current in the beginning is proportional to the third power of the tension V, namely: tan α = const. V^3. The truth of this relation was proved by our tests.

According to the common theory, *i. e.* the so-called maximum electrical strength theory an insulating material exposed to a non-uniform electrical field should rupture as soon as the field—strength has passed a certain limit anywhere within the dielectric. But this conclusion has proved to contradict experience in many cases and may also not be justified by the author's theory. The dielectric is capable of withstanding an overstraining without damage, supposing that the less strained parts of the dielectric contained in the path of the current prevent the latter from increasing excessively. Rupture does not occur before the condition of the *whole* path of the current has become unstable.

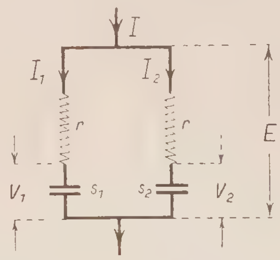

Fig. 18

The conformity of all these theoretical conclusions to the observed tests, may, I believe, serve as a strong support, for the correctness of the idea that the electrical rupture of solid dielectrics is a phenomenon of overheating by current.

By this explanation the breakdown phenomena, mysterious as they have been hitherto, are shown to be the consequence of well-known physical laws and at the same time are opened to numerical treatment.

Appendix

1. Calculation of the Breakdown-Characteristics

As explained before, breakdown occurs as soon as the condition in a thread-shaped channel through the insulating material has become unstable. This idea, as represented by Fig. 2, leads to a numerical calculation by the following assumptions.

a. Only the resistance of the thread-shaped channel shall vary with the voltage while the resistance of the

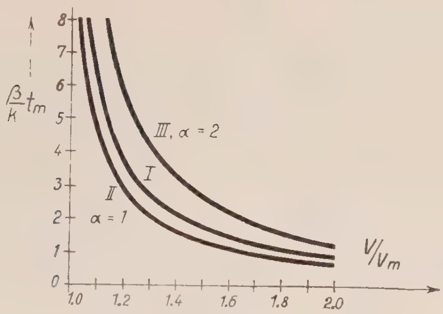

Fig. 19

remainder of the dielectric is supposed to be independent of the voltage variations.

b. The resistance of the thread is a function of the temperature. The calculations are based upon the following resistance laws:

$$R = R_0 \, e^{-\alpha \theta} \qquad \text{(I)}$$

$$R = R_0 \, (1 - \theta / T)^{\alpha} \qquad \text{(II)}$$

$$R = R_0 \left(\frac{T}{T + \theta} \right)^{\alpha} \qquad \text{(III)}$$

θ = temperature of the thread above that of the surrounding parts of the insulator; R_0 = resistance of the thread at the initial temperature ($\theta = 0$), R = resistance of the thread at the temperature θ, α, T = constants.

By the Law I the resistance R decreases with increasing temperature according to an exponential function (Fig. 15, at the left), but does not vanish for any finite value of the temperature.

By the resistance Law II, R vanishes at a finite temperature T, which may be called the burning temperature of the insulating material. According to the value of the exponent α, the resistance decreases in a linear manner ($\alpha = 1$), or with slackening ($\alpha > 1$), or with increasing speed ($\alpha < 1$), see Fig. 15.

According to Law III, the resistance decreases continuously with the temperature, the rate of diminution being the larger the higher the exponent α is chosen (Fig. 15, at the right).

For most of the dielectrics investigated until now, the resistance Law III seems to give the best approximation to the actual variation of the resistance with the temperature.

c. If the voltage V be increased so slowly that the stationary condition is reached for any value of V, the power $V\,I$ absorbed in the thread must be equal to the quantity of heat carried off to the surroundings. This quantity increases with the temperature θ. If we suppose the heat to be carried mainly by conduction, the flow of heat will be in proportion to the temperature, and the condition of equilibrium is expressed by the equation

$$V\,I = \beta\,\theta \qquad \text{(IV)}$$

β being the coefficient of heat conduction. In the case that radiation of heat is to be taken into account, the flow of heat from the thread to the surroundings will increase with a higher power of the temperature, according to the equation

$$V\,I = \beta\,\theta'' \qquad \text{(V)}$$

$$n > 1$$

The following considerations are confined to the equation (IV), the results obtained in this way being in sufficient agreement with the observed data.

The equation of the $V\,I$—characteristics is obtained by eliminating the temperature θ from (IV) with the aid of the resistance law.

By Law I:

$$1/R = I/V = 1/R_0 \, e^{\alpha \theta} = 1/R_0 \, e^{\frac{\alpha}{\beta} V I}$$

or

$$f(V, I) = I/V - 1/R_0 \, e^{\frac{\alpha}{\beta} V I} = 0 \qquad \textbf{(1)}$$

The characteristics computed from (1) have the shape represented by Fig. 3. The breakdown voltage V_m and the corresponding current I_m are obtained from the maximum condition

$$\frac{\partial f}{\partial I} = 0, \text{ for } V = V_m, \ I = I_m \qquad \textbf{(1a)}$$

in connection with the equation of the characteristic curve

$$f(V_m, I_m) = 0 \qquad \textbf{(1b)}$$

From (**1**), (**1a**), (**1b**), we get

$$1/V_m - \alpha/\beta \, V_m/R_0 \, e^{\frac{\alpha}{\beta} V_m I_m} = 0$$

$$I_m/V_m - 1/R_0 \, e^{\frac{\alpha}{\beta} V_m I_m} = 0$$

and further

$$\left.\begin{aligned} V_m &= \sqrt{\frac{\beta R_0}{\alpha e}}\,; \quad I_m = \sqrt{\frac{\beta e}{\alpha R_0}} \\ R_m &= V_m/I_m = R_0/e = 0{,}36\, R_0 \end{aligned}\right\} \qquad \textbf{(2)}$$

β and R_0 are both in direct proportion to the length of the thread, *i. e.* to the thickness of the insulating material. Consequently the *breakdown voltage V_m is in direct proportion to the thickness of the dielectric,* and the current I_m is independent of the thickness.

Supposing the *resistance law II*, we get

$$1 - \theta/T = (R/R_0)^{1/\alpha} = \left(\frac{V}{I R_0}\right)^{1/\alpha}$$

But from (IV) $\theta = \dfrac{V I}{\beta}$ and

$$f(V_1 I) = 1 - \frac{V I}{\beta T} - \left(\frac{V}{I R_0}\right)^{1/\alpha} = 0 \qquad \textbf{(3a)}$$

(3a) is the equation of the characteristics. By a reasoning similar to that given above, we find

$$\left(\frac{\partial f}{\partial I}\right)_{V_m 1 I_m} = -\frac{V_m}{\beta T} + (V_m/R_0)^{1/\alpha} \cdot I_m/\alpha^{\frac{1}{\alpha}\frac{\alpha}{\alpha}} = 0$$

$$(V_{m1} I_m) \qquad = 1 - \frac{V_m I_m}{\beta T} - \left(\frac{V_m}{I_m R_0}\right)^{1/\alpha} = 0$$

$$V_m = \frac{\alpha^{\alpha/2}}{(1+\alpha)^{\frac{1+\alpha}{2}}} \sqrt{R_0 \beta T}\,;$$

$$I_m = \frac{(1+\alpha)^{\frac{\alpha-1}{2}}}{\alpha^{\alpha/2}} \sqrt{\frac{\beta T}{R_0}} \qquad \textbf{(3b)}$$

$$R_m = V_m/I_m = R_0 \left(\frac{\alpha}{1+\alpha}\right)^{\alpha}$$

As before with the resistance law (I) V_m is in direct proportion to the thickness of the dielectric, while I_m is independent of it.

With the special value $\alpha = 1$ (linear decrease of resistance).

$$V_m = 1/2 \sqrt{R_0 \beta T}\,; \quad I_m = \sqrt{\frac{\beta T}{R_0}} \qquad \textbf{(3c)}$$

With the *resistance law III*, the equation of the characteristic takes the form

$$f(V, I) = V(\beta T + V I)^{\alpha} - R_0 (\beta T)^{\alpha} I = 0 \qquad \textbf{(4a)}$$

By proceeding in the same way as before, we obtain the expressions

$$V_m = \frac{(\alpha-1)^{\frac{\alpha-1}{2}}}{\alpha^{\alpha/2}} \sqrt{u_0 \beta T} \qquad \textbf{(4b)}$$

$$I_m = \frac{\alpha^{\alpha/2}}{(\alpha-1)^{\frac{\alpha+1}{2}}} \sqrt{\frac{\beta T}{R_0}} \qquad \textbf{(4c)}$$

As a very remarkable fact we note that V_m and I_m are depending on the thickness of the dielectric, on the initial resistance and on the heat conduction coefficient β by the same functions as in the cases of the resistance Laws I and II.

The special value $\alpha = 1$ gives $I_m = \infty$ and $R_m = 0$; the characteristic approaches asymptotically the value V_m with increasing current. The values of α below 1 are without physical meaning in the theory developed here, as they lead to imaginary values of V_m.

As the three resistance laws *I, II, III* lead to quite similar results, we may imagine the existence of a general law

$$V_m = \text{constant } \sqrt{R_0 \beta},$$

which is independent of the particular resistance law. That this assumption is true can be shown as follows.

From (IV) we get

$$\beta \theta R = V^2$$

Now R is a function of the temperature, and we may put

$$R = R_0 \varphi(\theta)$$

φ being a function of θ with the initial value $\varphi(o) = 1$ and continuously decreasing with increasing temperature (Fig. 16).

From the preceding equations we obtain

$$\theta \varphi(\theta) = \frac{V^2}{\beta R_0}$$

Now the expression on the left side means the product of the ordinates of the curve $\varphi(\theta)$ and the straight line θ and is represented by the curve shown in Fig. 16, having an apex.[6] As the ordinate M of the apex does not depend on β or R_0, we have

$$V_m = \sqrt{M \beta R_0} = \text{const} \sqrt{\beta R_0},$$

q. e. d.

By determinating the breakdown characteristics *experimentally*, the current I observed is composed of the current through the breakdown channel and the current through the remaining part of the dielectric. If we suppose, that there is only one breakdown channel, *i. e.* one thread, the resistance of which depends on the voltage, while the resistance of the remainder is constant, the characteristic of the whole dielectric may be plotted by the following construction (Fig. 17). The characteristic of the breakdown channel is given by the curve 1, and the characteristic of the healthy parts of the dielectric by the straight line 2, the characteristic 3 of the whole of the dielectric is found by adding the ordinates of the curves 1 and 2.

If there are existing more than one weak channel the total characteristic is composed of the individual characteristics in a rather complicated manner. Fig. 18 represents the conditions with two weak channels s_1 and s_2. In series with each one we have the resistance r. With the same total voltage E applied, the two channels take different currents I_1 and I_2 and in

6. The existence of an apex is bound to the condition that, with θ increasing, ϕ decreases ultimately faster than $1/\theta$ does, which condition is fulfilled in all practical cases.

consequence are stressed with different voltages V_1 and V_2. But by the experimental determination of the characteristics the total current $I_1 + I_2$ is obtained as a function of a *mean* voltage, V, which is taken as the tension acting upon the weak threads. As the connection of V to the V_1 and V_2 is not known, we may say nothing but that the total characteristic must be an intermediate curve between the individual characteristics.

2. Dependence of the Breakdown Voltage on the Frequency

In the preceding considerations the weak thread is supposed to be heated only by the current according to Joule's law. With alternating voltages an additional heating occurs by dielectric losses. These are in direct proportion to the frequency of the current and to the square of the tension. The power produced in a thread of the capacity C amounts to

$$N = \omega C V^2 \cos \varphi = G V^2,$$

ω being the circular frequency, $\cos \varphi$ the power factor of the dielectric and G the dielectric leakance of the thread, $G = \omega C \cos \varphi$. In order to simplify the corrections in the preceding considerations required by the dielectric losses, we shall suppose the dielectric power factor to be independent of the temperature. In consequence G is a constant quantity for any given frequency.

The combined resistance, composed of the variable ohmic resistance R of the thread and the leakance G has the value

$$\overline{R} = \frac{R \cdot 1/G}{R + 1/G} = \frac{R}{1 + R G}$$

$\overline{R}$ determines the proportion V/I, V being the voltage acting on the thread and I the component of the total current being in phase with V[7]. I is the sum of the ohmic current V/R and the leakage current $G V$. In the equation.

$$V/I = \frac{R}{1 + R G}$$

the resistance law (either I, or II, or III) has to be introduced, the temperature θ being determined according to (IV) by the power $V I$ and the heat conduction coefficient β.

With the resistance Law I, we get

$$V/I = \frac{R_0 e^{-\frac{\alpha}{\theta}}}{1 + G R_0 e^{-\alpha\theta}} = \frac{R_0 e^{-\frac{\alpha}{\beta} V I}}{1 + G R_0 e^{\frac{-\alpha}{\beta} V I}} \tag{6}$$

or

$$(V, I) = V + V G R_0 e^{-\frac{\alpha}{\beta} V I} - I R_0 e^{-\frac{\alpha}{\beta} V I} = 0 \tag{7}$$

7. The capacitive component of the current does not contribute to the heating of the thread and may therefore be left out of consideration.

This is the equation of the characteristic. If we apply the maximum condition

$$\frac{\partial f}{\partial I} = 0, \quad \text{for } V = V_m, \quad I = I_m,$$

$$I_m = \beta/\alpha \, 1/V_m + G V_m \tag{8}$$

The expression at the right of (**8**) has to be introduced into (**7**) in order to eliminate I_m. This done the factor

$$e^{-\frac{\alpha}{\beta} V_m I_m} = e^{-1 - \frac{\alpha}{\beta} G V_m^2} = 1/e \; e^{-\frac{\alpha}{\beta} G V_m^2}$$

appears. At tensions of the order of V_m the power absorbed by dielectric losses comes only to a small fraction of the power absorbed according to Joule's law. Therefore the exponent $x = \alpha/\beta \, G V_m^2$ is small as compared with unity, and in consequence

$$e^{-x} = 1 - x$$

holds very approximately, i. e.:

$$e^{-\frac{\alpha}{\beta} V_m I_m} = 1/e \left(1 - \alpha/\beta \, G V_m^2\right) \tag{9}$$

With (**8**), (**9**) and (**7**):

$$V_m^4 - \frac{e \beta (1 + R_0 G/e)}{\alpha G^2 R_0} V_m^2 + \frac{\beta^2}{\alpha^2 G^2} = 0$$

$$V_m^2 = \frac{e \beta (1 + R_0 G/e)}{2 \alpha G^2 R_0} \pm \sqrt{\frac{e^2 \beta^2 (1 + R_0 G/e)^2}{4 \alpha^2 G^4 R_0^2} - \frac{\beta^2}{\alpha^2 G^2}}$$

Only the root with the negative sign has a physical meaning as it gives for $G = 0$ the correct value of V_m according to equation (**2**), while the root with the positive sign leads to $V_m = \infty$ for $G = 0$. Therefore

$$V_m = \frac{e \beta (1 + R_0 G/e)}{2 \alpha G^2 R_0} \left[1 - \sqrt{1 - \frac{4 G^2 R_0^2}{e^2 (1 + R_0 G/e)^2}} \right]$$

With G small, as supposed, the root may be expanded according to the binomial formula, and nothing but the first term of the expansion need to be retained. By this procedure we get the final expression

$$V_m = \sqrt{\frac{\beta R_0}{\alpha e}} \left(1 - \frac{G R_0}{2 e} \right) \tag{10}$$

The first term on the right is the breakdown voltage with $G = 0$ (see equation 2), *i. e.* for direct current. The second term shows the decrease of the breakdown voltage with increasing frequency. In particular it is seen from (**10**) that V_m is a linear function of the frequency[8], as the same is true for G.

If we start from the resistance Law II or III, the same procedure as before may be followed. The mathe-

8. Of course the linear law holds only for low frequencies, for which G is small, as supposed.

matical derivations being of rather little interest only the results are given here.

Resistance law II, $\alpha = 1$:

$$V_m = 1/2\sqrt{\beta R_0 T}\left(1 - \frac{R_0 G}{4}\right) \tag{11}$$

$$I_m = \sqrt{\frac{\beta T}{R_0}}\left(1 + \frac{R_0 G}{2}\right) \tag{12}$$

Resistance law III:

$$V_m = \frac{(\alpha - 1)^{\frac{\alpha-1}{2}}}{\alpha^{\alpha/2}}\sqrt{\beta R_0 T}\left[1 - \left(\frac{\alpha - 1}{\alpha}\right)^{\alpha}\frac{R_0 G}{2}\right] \tag{13}$$

As before with the Law I, we find a linear decrease of the breakdown voltage with increasing frequency, caused by the dielectric losses (see Fig. 13).

3. Influence of Time on the Breakdown Phenomena

According to the hypothesis (c) in part (1), we have assumed the voltage to be varied so slowly, that a stationary condition is reached for any value V of the voltage. This assumption shall be abandoned now. As an example we shall consider the case of a voltage V larger than the breakdown voltage V_m being suddenly applied to the dielectric at a certain moment $t = o$. We know from experience that the current passing through the dielectric increases continually (see Fig. 14, at the right) until the dielectric breaks down. The time t_m elapsed from the beginning of the phenomenon is obviously the shorter, the larger the voltage V has been chosen in proportion to V_m.

At any time between o and t_m the power $V\,I$ respectively V^2/R absorbed from the thread in which the rupture shall occur has to cover the flow of heat to the surroundings and the amount of heat stored up in the material forming the thread.

As the flow of heat equals $\beta\,\theta$ and the amount of heat stored up per second is expressed by $k\,\frac{d\theta}{dt}$, k being the heat—capacity of the thread, the law of conservation of energy takes the form

$$\beta\,\theta + k\frac{d\theta}{dt} = V^2/R \tag{VI}$$

R is a function of temperature, as per example, given by (I), (II) or (III).

Before we base further calculations upon one of the particular resistance Laws I, II or III, a general theorem shall be deduced, which is independent of the assumption of any special resistance law.

By differentiating Ohm's equation $I = V/R$ we get

$$\frac{dI}{dt} = -\frac{V}{R^2}\cdot\frac{dR}{d\theta}\cdot\frac{d\theta}{dt} \tag{14}$$

From this expression we may calculate the *initial gradient of current, i. e.* the slope of the tangent on the curve at the right of Fig. 14 at $t = 0$. In this point we have $\theta = o$ and therefore, from (VI)

$$k\frac{d\theta}{dt} = V^2/R_0 \tag{15}$$

The coefficient of resistance—variation with temperature $\left(-\frac{dR}{d\theta}\right)$ has, for $\theta = 0$, a certain positive value, say c.

With these terms we get

$$\left(\frac{dI}{dt}\right)_{t=o} = \frac{c}{k R_0^3}\cdot V^3 \tag{16}$$

In words: *The initial current gradient is in proportion to the third power of the voltage applied.*

By using the resistance Law I, we get from (VI) the differential equation

$$\beta\,\theta + k\frac{d\theta}{dt} = V^2/R_0\,e^{\alpha\theta} \tag{17}$$

We may separate the variables in (**17**) and then integrate both sides:

$$t = k\int_o^{\theta}\frac{d\theta}{V^2/R_0\,e^{\alpha\theta} - \beta\,\theta} \tag{18}$$

From (**18**) the time t that elapses until a certain temperature θ in the thread is reached may be numerically computed without difficulty. With θ the resistance R is obtained from (I); R gives $I = V/R$. In this way the curve at the right of Fig. 14 can be theoretically calculated.

The breakdown time t_m follows from (**18**) by putting $\theta = \infty$:

$$t_m = k\int_o^{\infty}\frac{d\theta}{V^2/R_0\,e^{\alpha\theta} - \beta\,\theta} \tag{19}$$

Write (**19**) in the form

$$t_m = k/\beta\int_o^{\infty}\frac{\frac{\beta R_0\,e^{-\alpha\theta}}{V^2}}{1 - \theta\frac{\beta R_0}{V^2}e^{-\alpha\theta}}\,.\,d\theta$$

and develop the denominator according to the formula of the geometrical series

$$\frac{1}{1-x} = 1 + x + x^2 + x^3 + \ldots$$

$$t_m = k/\beta \int_0^\infty d\,\theta \left[\left(\frac{\beta R_0}{V^2} \right) e^{-\alpha\theta} + \theta \left(\frac{\beta R_0}{V^2} \right)^2 e^{-2\alpha\theta} + \ldots \right]$$

By the application of Euler's well-known Integral we get

$$t_m = k/\beta \left[\frac{\beta R_0}{\alpha V^2} + 1 \left(\frac{\beta R_0}{2 \alpha V^2} \right)^2 + 2 \left(\frac{\beta R_0}{3 \alpha V^2} \right)^3 + \ldots \right]$$

According to (**2**), we have $\beta R_0 / \alpha e = V_m^2$. We introduce this term in the foregoing equation and obtain the final expression

$$t_m = k/\beta \left[e (V_m/V)^2 + 1\,! \,(e/2)^2 \, (V_m/V)^4 + 2\,! \,(e/3)^3 \,(V_m/V)^6 + \ldots \right] \qquad (\mathbf{21})$$

The expression within the brackets depends on (V_m/V) exclusively and may be easily calculated as the series converges rapidly. (**21**) is represented by Fig. 14 at the left.

A very remarkable result follows immediately from (**21**): *If we plot $\beta t_m/k$ against V/V_m, we obtain the same curve from any kind of insulating material.* In other words: *The breakdown curve $t_m = f(V)$ for a certain dielectric may be transferred into the curve for any other dielectric simply by changing the scale.*

The theorem just mentioned has been obtained by assuming the resistance Law I. But we shall find it true with each of the other resistance Laws II and III too.

With the Law II the deductions shall be confined to the case $\alpha = 1$, according to

$$R = R_0 (1 - \theta/T)$$

The calculations are omitted, as they do not show anything of interest; the result is

$$t_m = k/\beta \frac{2 \arcsin (V_m/V)}{\sqrt{(V/V_m)^2 - 1}} \qquad (\mathbf{22})$$

By (**22**) $t_m \, \beta/k$ is, as before, *a function of V/V_m only.*

In the case of the resistance Law III we have

$$\beta\,\theta + k \frac{d\,\theta}{d\,t} = V^2/R_0 \,(1 + \theta/T)^\alpha$$

We put, for abbreviation

$$\theta/T \qquad (\mathbf{23a})$$

and

$$\frac{\beta\,T\,R_0}{V^2} = A \qquad (\mathbf{23b})$$

By introducing these terms, separating the variables and integrating:

$$t_m = k/\beta \int_0^\infty \frac{A\,d\,\eta}{(1 + \eta)^\alpha - A\,\eta} \qquad (\mathbf{23})$$

By (**48**):

$$A = (V_m/V)^2 \frac{\alpha^\alpha}{(\alpha - 1)^{\alpha - 1}} \qquad (\mathbf{23c})$$

Again we find, according to (**23**) *$\beta t_m/k$ to be a universal function of the proportion V/V_m.*

For arbitrarily given values of α, the integral on the right of (**23**) can only numerically be computed. But for $\alpha = 2$ it may be expressed by known functions:

$$\left.\begin{aligned} t_m &= k/\beta \frac{A}{\sqrt{A - 1/4\,A^2}} \left[\pi/2 - \arctan \frac{1 - 1/2\,A}{\sqrt{A - 1/4\,A^2}} \right] \\ A &= 4\,V_m^2/V^2 \end{aligned}\right\} \qquad (\mathbf{23d})$$

In Fig. 19 the relations given by equations (**21**), (**22**) and (**23d**) are represented for the purpose of comparison. Table I contains the numerical values within a larger range.

TABLE I

V/V_m	$\beta t_m/k$ Resistance Law: I	II	III
1	∞	∞	∞
1,11	5,805	4,625	9,26
1,25	3,133	2,473	4,95
1,43	2,055	1,520	3,12
1,67	1,310	0,965	1,93
2,00	0,823	0,604	1,21
2,50	0,490	0,359	0,7186
3,33	0,261	0,192	0,3844
5,00	0,1115	0,0822	0,1642
10,00	0,0274	0,0201	0,0403

The values below III are very nearly twice as large as the corresponding values below II, while the values below I differ from those below II approximately by the factor 1.35. According to these relations, each of the 3 curves in Fig. 19 may be turned into the other one simply by changing the time-scale. In consequence it is impossible to decide only by breakdown trials which particular resistance law holds good. This would require an independent determination of the thermical constant k/β.

With a proper time scale the theoretical curves represent the observed data as well as might be expected if the heterogeneousness of the dielectrics and the corresponding dissemination of the breakdown voltages are taken into account.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

Convention Activities of the Institute

Plans are well under way for the coming conventions. At the Midwinter which will be held in New York, February 14, 15, 16 and 17, some very interesting technical papers will be presented supplemented by an evening session at which the Chicago Section has been invited to listen and to discuss papers through the use of telephone connections and the loud speakers.

Tentative arrangements for the Midwinter Convention call for registration on the morning of the first day followed by an afternoon session under the auspices of the Transmission and Distribution Committee at which papers will be presented on cable design, operation, and tests including some specialized discussion of dielectrics.

In the evening a joint session with Chicago is contemplated through the use of telephones and loud speakers. At this meeting a paper on loud speakers is to be followed by an illustrated lecture on European railroad electrification.

On Thursday morning, the second day of the convention several papers are available for presentation under the auspices of the Telephone and Telegraph Committee. Among the contemplated papers are authoritative treatments of machine switching, transmission over long land cables, the use of alternating current in ocean cable telegraphy and the use of wave antennas.

In the afternoon papers of general interest are to be presented including a splendid discussion of railroad electrification and electric furnaces. An interesting feature of the session will be the demonstration of some new kinematic devices applied to machines and transmission lines.

The Edison Medal presentation accompanied by addresses by prominent physicists and engineers are tentative features for Thursday evening.

On Friday the morning session will be under the auspices of the Electro Physics Committee where new advances in the art will be presented by Dr. Kennelly, Dr. Carl Hering, Messrs. Slepian and Peters, Nottingham, McEachron and other specialists. During the year many new developments have occurred which afford splendid material for this meeting. In the afternoon a session is planned for the Meters and Measurements Committee which has prepared papers on the application of thermocouples and new developments in meters and measurements.

One of the annual features of the Midwinter Convention is the Institute dinner-dance which will be held on Friday evening. Saturday morning is planned for inspection visits to points of interest to engineers in New York City

OTHER CONVENTIONS UNDER WAY

Preparations are well in hand for other conventions of the Institute. The Pittsburgh Meeting in April will accent transmission and distribution line practise and protection, and several splendid papers are being prepared. For the June Meeting at Swampscott a special feature will be railroad electrification and a complete discussion of the subject is planned. For the Pacific Coast Convention at San Francisco in September papers are already in preparation and the great advances in transmission line practise, transformer practise and substation practise will feature the meeting.

Nomination and Election of Institute Officers for 1923-1924

As provided in Section 19 of the Institute By-Laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1923, by the petition or by the separate endorsement in writing, of not less than twenty-five members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1923. For the conveniences of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available. A member is not limited in the number of candidates he may endorse in this manner.

The officers to be elected are: A President and a Treasurer for the term of one year each, five Vice-Presidents for the term of two years each (one from each of the even numbered geographical districts), and three Managers for the term of four years each.

The five even numbered districts from which Vice-Presidents are to be chosen at the May 1923 election are as follows:

2. Middle Eastern: Delaware, District of Columbia, Maryland, New Jersey (exclusive of N. Y. Section territory), Ohio, Pennsylvania, West Virginia.

4. Southern: Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia.

6. North Central: Colorado, Iowa, Minnesota, Nebraska, North Dakota, South Dakota, Wyoming.

8. Pacific: Arizona, California, Nevada, Hawaii, Philippines.

10. Canada.

According to the revised Constitution, while one Vice-President must be elected from each of the five even numbered districts, this does not debar members in one district, if they so wish, from nominating and voting for a candidate in another district. When the votes are counted the candidate for Vice-President having the largest vote in each district will be elected to that particular office for that district, irrespective of the fact that he may have polled a smaller number of votes than a candidate standing second in another district.

For the information of members the full text of revised sections of the Constitution and By-Laws applying to Officers, nominations, elections, etc., are printed below:

CONSTITUTION

Sec. 23. The officers of the Institute shall be a President, one Vice-President from each geographical district as defined in the By-Laws, twelve Managers, a Secretary and a Treasurer.

Sec. 24. The President, the Secretary and the Treasurer shall hold office for one year, the Vice-Presidents for two years and the Managers for four years. The President and Managers shall not be eligible for immediate re-election to the same office. No Vice-President or Manager who has served continuously in one or more offices, and whose combined terms shall have aggregated six years or more shall be eligible for immediate election to the office of Manager or Vice-President. At each Annual Meeting the President, the requisite number of Vice-Presidents to fill vacancies caused by expiration of terms, three Managers and the Treasurer shall be elected by the membership, and their terms of office shall commence on the first of August next succeeding their election................

Sec. 24A. At the election of Vice-Presidents held in 1921 there shall be elected one Vice-President from each geographical district, those from the odd-numbered districts to serve for one year each, and those from the even-numbered districts two years each. All Vice-Presidents elected thereafter shall serve for two years each. In the event of a change in the geographical districts, the Vice-Presidents then in office shall complete their terms. In case of revisions of the geographical districts, the Board of Directors shall have the power to elect a Vice-President from each district not represented to serve until the next election covering these districts.

BY-LAWS

Sec. 19. In addition to the names of the incumbents of office the Secretary shall publish on the "form showing offices to be filled at the ensuing annual election in May provided for in Article VI, of the Constitution, the names, as candidates for nomination, of such members of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than twenty-five members, received by the Secretary of the Institute in writing by January twenty-fifth of each year; provided, however, that any candidate proposed for nomination by petition may withdraw his name by written communication to the Secretary, and any name so withdrawn prior to the printing of the form shall not be published.

The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the December and January issue of each year's Journal and shall be reproduced on the form above referred to.

Sec. 21. There shall be ten geographical districts grouped as follows: (For the balance of this Section describing districts see By-laws and map.)

Sec. 21A. Should the territory of any Institute Section lie in more than one geographical district as defined above, then the entire territory of said Section shall be considered as belonging to the geographical district in which the headquarters of the Section are located.

Professional Ethics

In accordance with the recommendation of the A. I. E. E. Committee on Code of Principles of Professional Conduct that its findings and decisions be published in the Institute Journal, which recommendation was approved by the Directors, there was published in the April 1922 Journal the action of the Committee in connection with the case of a member brought to their attention. In concluding this particular case the Committee has directed that the following note be published:

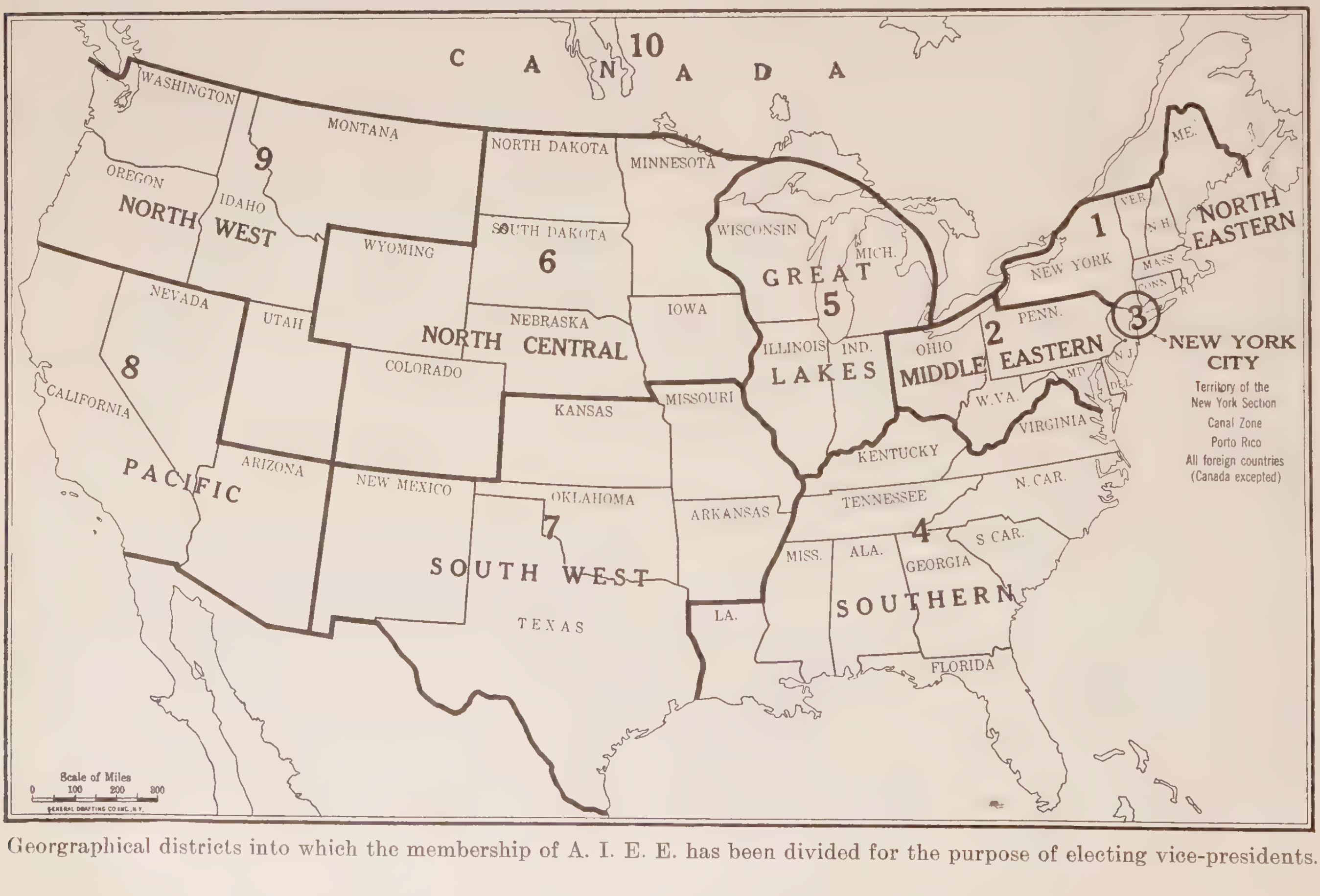
"Referring to the case of a member who without authority stated in a publication of his that the contents were to be presented before the Institute and in which matter the Institute's Committee on Code of Principles of Professional Conduct decided that the member must remove this statement and recall outstanding copies, the Secretary has received assurance that these requirements have been complied with and the incident is therefore closed."

Final Plans Complete for Power Exposition

A hundred and fifty thousand visitors are expected to attend the National Exposition of Power and Mechanical Engineering at the Grand Central Palace from December 7-16. In addition to the underlying purpose of bringing together material for display for the benefit of engineers so that they may keep in touch with the latest devices, the need for greater understanding of power development and conservation of natural resources will be met in the educational nature of many of the exhibits shown. One of the interesting exhibits will show the hydroelectric power development in the Southern states. An invitation is extended by the Committee to every member of the A. I. E. E. and an Institute badge or membership card will serve as a pass.

Connecticut Section Meeting Attended by 2475

The 11th meeting of the Connecticut Section which was held in Woolsey Hall, Yale University, New Haven on Friday evening, October 27, 1922 jointly with the Yale Branch proved not only



Georgraphical districts into which the membership of A. I. E. E. has been divided for the purpose of electing vice-presidents.

very interesting but also a great success with an attendance of 2475.

Chairman Everit who presided after outlining the early activities of the Institute in the communication field introduced Professor Charles F. Scott, Past President of the A. I. E. E. and first Chairman of the Connecticut Section. Prof. Scott spoke of the demarkation of the communication and power groups as resting principally on the relative magnitudes of the currents and voltages employed in the two fields. President Frank B. Jewett then outlined the activities of the Institute and pointed out how the growth of the Section idea had modified the functioning of the Institute. The President was followed by E. B. Craft, Chief Engineer, Western Electric Company whose general topic was "Some Recent Developments in Telephony and Telegraphy," demonstrating the points of his talk with equipment installed for the purpose notably a demonstration of carrier currents. A loud speaking telephone had been placed in operation and enabled everyone to hear in a hall of bad acoustic properties without speaker exceeding a conversational tone. The "talking movie" was then demonstrated. Because of the general nature of the meeting invitations to attend were extended and enthusiastically accepted by the membership of the Chamber of Commerce, the Rotary, Kiwanis, Lions Club, and Southern New England Telephone Company force.

Future Section Meetings

Boston.—January 9, 1922. Subject: "The Double Method of Testing Insulators." Speaker: Mr. Frank C. Doble. This meeting will be in conjunction with the electrical students of Massachusetts Institute of Technology.

February 13, 1922. This will be the annual dinner of the Affiliated Technical Societies of Boston. It will be followed by motion pictures and address by Mr. A. A. Northrop of Stone & Webster, Inc., Boston. The subject shown will be the "Caribou Hydroelectric Development."

Detroit-Ann Arbor.—January 12, 1923. Subject: "Experiences and Problems Encountered in the Electric Transportation System of a Large City." Speaker: Mr. H. M. Gould, Electrical Engineer, Dept. Street Railways, City of Detroit.

February 9, 1922. Mr. D. H. Baer, Chief Electrician, Morgan & Wright Co. There will be a general description of the various kinds of electrical equipment required in a mammoth modern tire-making plant.

Pittsburgh.—December 12, 1922. Subject: "Lightning Arresters and Lightning Protection." Speaker: Mr. D. W. Roper, Supt. of Street Dept., Commonwealth Edison Co., Chicago.

January 9, 1923. Subject: "A-C. Substations for City, Industrial and General Distribution Work." Speaker: Mr. A. H. Kehoe., Supt. of Transmission and Distribution, United Electric Light & Power Co., New York.

New York.—The Program Committee of the N. Y. Section has been extremely fortunate in obtaining as a speaker for the evening of January 19, 1923, Dr. M. I. Pupin, Professor of Electro-Mechanics of Columbia University. Dr. Pupin has selected as his subject "The Modern Physics," a topic which, in the hands of such an authority and in addition gifted orator as Dr. Pupin, should prove of intense interest to every member of the Section.

Pittsfield.—December 21, 1922. Speaker: Dr. Harry A. Garfield, President, Williams College. Subject to be announced.

January 3, 1923. Speaker: Prof. V. Karapetoff, Cornell University. Musical Lecture-Recital, Piano and five-string cello. Miss Tuttle, Ithaca, N. Y., accompanist.

January 4, 1923. Subject: "Resonance and Oscillation." Speaker: Prof. V. Karapetoff, Prof. Electrical Engineering, Cornell University.

January 18, 1922. Subject: "Power Development at Niagara." Speaker: Mr. J. L. Harper, Vice-Pres. and Chief Engineer, Niagara Falls Power Co.

Schenectady.—January 5, 1923. Speaker: Prof. V. Karapetoff, Cornell University.

Toronto.—January 12, 1923. Subject: "Industrial Heating." Speaker: Not chosen.

January 26, 1923. Subject: "Large Power Distribution and Control." Speaker: Mr. P. E. Hart.

Worcester.—December 21, 1922. Subject: "Vacuum Tubes." Speaker: Mr. H. H. Newell, Electrical Dept., Worcester Polytechnic Institute.

January 18, 1923. Subject: "The New England Power System—Economic Aspects, Financial Structure, Organization." Speaker: Mr. S. C. Moore, General Manager, New England Power Co.

Charles A. Coffin Foundation

As an expression of appreciation of Mr. Charles A. Coffin's great work not only for the General Electric Company but also for the entire electrical industry, and with the desire to make this appreciation enduring and constructive as Mr. Coffin's life and work have been, the Board of Directors of the General Electric Company created on his retirement "the Charles A. Coffin Foundation."

The company has set aside a fund of $400,000, the income from which amounting to approximately $20,000 per year, will be available for encouraging and rewarding service in the electrical field by giving prizes to its employes, recognition to lighting, power and railway companies for improvement in service to the public, and fellowships to graduate students and funds for research work at technical schools and colleges.

The foundation will be controlled and administered by a Foundation Committee appointed by the Board. This committee, within the limits of the purposes for which the foundation is created, will have power to change the conditions applicable to the distribution of the fund and the amounts for each particular purpose.

The committee proposes to distribute the income of the Foundation as follows:

First. Eleven thousand dollars in prizes for the most signal contributions by employes of the General Electric Company toward the increase of its efficiency or progress in the electrical art. Particularly, the prizes are to further encourage suggestions from workmen. With each prize, the company will give a certificate of award.

Foremen's prizes are to be awarded for the best department, taking into account its appearance, efficiency of operation, and conditions which add to the better conduct of the work and the welfare of the employes.

All employes of the company, except executive officers, heads of departments, works managers, superintendents, district office managers and similar executives, are eligible for such prizes.

In works where employes' representation has been adopted such representatives will cooperate with the prize committee in awarding prizes in such works.

Second. A gold medal, to be known as the "Charles A. Coffin Medal," will be awarded annually to the public utility operating company within the United States which, during the year, has made the greatest contribution towards increasing the advantages of the use of electric light and power for the convenience and well-being of the public and the benefit of the industry. The company receiving the medal will also receive one thousand dollars for its employes' benefit or similar fund.

A committee to be named by the National Electric Light Association and known as the "Charles A. Coffin Prize Committee of the National Electric Light Association," which shall consist of its President, Chairman of its Public Policy Committee and a third member nominated by them, will award this medal acting with the advice and cooperation of a committee appointed

by the Foundation Committee. The expenses of the committee are to be paid out of the income of the foundation.

Third. A gold medal, to be known as the "Charles A. Coffin Medal," will be awarded annually to the electric railway company within the United States which, during the year, has made the greatest contribution towards increasing the advantages of electric transportation for the convenience and well-being of the public and the benefit of the industry. The company receiving the medal will also receive one thousand dollars for its employes benefit or similar fund.

A committee, to be named by the American Electric Railway Association and known as the "Charles A. Coffin Prize Committee of the American Electric Railway Association," which shall consist of its President, the Chairman of the Committee on Policy, and a third member nominated by them, will award this medal acting with the advice and cooperation of a committee appointed by the Foundation Committee. The expenses of the committee are to be paid out of the income of the foundation.

Fourth. Five thousand dollars is to be awarded annually for fellowships to graduates of American colleges and technical schools who, by the character of their work, and on the recommendation of the faculty of the institution where they have studied, could with advantage continue their research work either here or abroad; or some portion or all of the fund may be used to further the research work at any of the colleges or technical schools in the United States. The fields in which these fellowships and funds for research work are to be awarded are, electricity, physics, physical chemistry.

A committee appointed by the Foundation Committee will award such fellowships and funds for research work, with the advice and cooperation of a committee of three, one to be appointed by each of the following, National Academy of Sciences, American Institute of Electrical Engineers, Society for the Promotion of Engineering Education. This Committee is to be known as the "Charles A. Coffin Fellowship and Research Fund Committee" and the Fellowships are to be known as the "Charles A. Coffin Fellowships." The expenses of the Committee are to be paid out of the income of the foundation.

Fifth. In each annual report of the General Electric Company a statement will be made of the awards under the "Charles A. Coffin Foundation," and other publicity will be given to such awards.

The Board of Directors of the General Electric Company has appointed as the "Charles A. Coffin Foundation Committee" the following officers of the Company; Mr. A. W. Burchard, Mr. J. R. Lovejoy, Mr. E. W. Rice, Jr., Mr. Gerard Swope, Mr. O. D. Young.

The Advisory Committee of the General Electric Company will administer the fund within the organization of the General Electric Company.

The following Committees, to administer the fund and to act with organizations outside the Company, have been appointed:

Committee to cooperate with the National Electric Light Association, Mr. A. H. Jackson, Vice-President, Mr. J. R. Lovejoy, Vice-President.

Committee to cooperate with the American Electric Railway Association, Mr. J. G. Barry, Vice-President, Mr. A. H. Jackson, Vice-President.

Committee to cooperate with the National Academy of Sciences, American Institute of Electrical Engineers and the Society for the Promotion of Engineering Education, Mr. E. W. Rice, Jr., Honorary Chairman, Mr. A. H. Jackson, Vice-President, Mr. W. R. Whitney, Directory of Research Laboratory.

American Engineering Standards Committee

SECTIONAL COMMITTEE ON COLORS FOR TRAFFIC SIGNALS

Thirty-nine men, representing as many administrative bodies, trade associations, scientific or technical societies, and government departments make up the Sectional Committee on Colors for Traffic Signals which was organized at a meeting in New York City, November 8, 1922, under the auspices of the American Engineering Standards Committee. The committee elected as its officers the following: Chairman, Charles J. Bennett, State Highway Commissioner of Connecticut, Vice-chairman, Dr. M. G. Lloyd, Secretary, Walter S. Paine.

COOPERATION BETWEEN FEDERAL SPECIFICATIONS BOARD AND INDUSTRY PROMOTED BY A. E. S. C.

An important step toward the elimination of the difference between specifications for government purchases and the usual practise of commercial suppliers has been taken through the appointment by the American Engineering Standards Committee, of a Standing Committee on Cooperation with the Federal Specifications Board. The members of the Committee on Cooperation. With the Federal Specifications are: A. H. Hall, Chairman, John A. Capp, Sullivan W. Jones. The appointment of this committee is the culmination of conferences between Dr. S. W. Stratton, Chairman of the Federal Specifications Board, other government officials and representatives of industry extending over a period of several months. It is expected that in future editions a large part of the specifications will go through the regular procedure of the American Engineering Standards Committee, in order that the industrial and government specifications may be unified, resulting in truly national specifications recognized by industry and government alike.

LEGAL PENALTIES WILL NOT BE INCLUDED IN APPROVED NATIONAL SAFETY CODES

Clauses relating to legal penalties or to methods of enforcement will not be included in the safety codes approved by the American Engineering Standards Committee. This policy was established at a meeting of the A. E. S. C. in New York on October 20.

This action was taken on the suggestion of the Safety Code Correlating Committee, which acts in an advisory capacity to the American Engineering Standards Committee in matters concerning safety codes.

It is the feeling both of the men engaged in the furtherance of standardization in industry and of practically all state officials that legal penalties for failure to conform with established state safety codes and methods of enforcement can best be decided by each state for itself.

A. E. S. C. APPOINTS SPECIAL COMMITTEE ON WOOD AND TUBULAR POLES

The American Engineering Standards Committee announces the appointment of a special committee to consider and make recommendations to the A. E. S. C. concerning the application of the American Electric Railway Association for approval as American Standards of its specifications for wood poles and tubular poles.

Twenty-one men, representing producers and consumers of both types of poles, as well as the public are on this committee. The importance of this subject to the lumber and iron industries, steam and electric railway, and other users of wood and tubular poles becomes apparent when it is known that several millions of poles are purchased each year.

AMERICAN ENGINEERING COUNCIL

TWO ENGINEERS NAMED ON PRESIDENT'S COAL FACT-FINDING COMMISSION

Appointments to the President's Coal Commission were completed on October 10th as follows:

John Hays Hammond, George Otis Smith, Thomas R. Marshall, Samuel Alschuler, Clark Howell, Edward T. Devine and Charles P. Neill.

The Federation recommended that two engineers be placed on the Commission. This request was complied with and the appointments of John Hays Hammond and George Otis Smith were made. The latter being one of several engineers recommended by the Federation.

At its organization meeting the Coal Commission elected Mr. Hammond chairman and retained the services of Edward E. Hunt, engineer and member of the Committee on Elimination of Waste, as secretary. A program of work was laid out and the object of the Commission was set as follows: to get all the essential facts touching the coal industry, to the end that practical measures may be found to insure a constant supply of coal at as reasonable prices as are consistent with fair wages and profits to those engaged in the industry. "The policy of the Commission will be to invite and welcome every suggestion and offer of assistance from the mine workers, operators, dealers, and consumers of coal. The Commission will from time to time make public its findings so that its report may be as complete and correct as possible when it is submitted to the President and Congress."

The Commission held a meeting with representatives of the United Mine Workers of America, National Coal Association and leading operators on Monday afternoon, October 23.

The Commission has started to use all the available resources of the Government in its fact-finding work.

NATIONAL RESEARCH COUNCIL

INFORMATION SERVICE

Electrical engineers know a great deal but even they frequently face serious need of relatively inaccessible information. The Engineering Societies Library with its associated information service and the headquarters of the Societies are invaluable sources of aid. Nevertheless there are demands which transcend their limits, for they specialize either in engineering or electrical engineering. It may be worth while then to note and remember that the National Research Council, Washington, D. C. has established a general clearing-house for scientific and technological information.

This is a free service, the purpose of which is the promotion of research and its applications in engineering and industry. Research Information Service covers all of the physical and biological sciences as well as engineering. It is favorably located and has unique informational advantages in the personnel of the National Research Council, innumerable contacts with scientists and industrialists and knowledge of the best informational resources and sources of this country and the world.

The National Research Council invites electrical engineers to utilize the new informational clearing-house by making known their needs. No charge will be made for service unless special search of literature, compilation of report or copying of records is necessary. The appropriate form of address is Information Service. National Research Council, Washington, D. C.

Researches in Insulation

The Research Committee of the Institute, and the Committee on Insulation, Engineering Division, National Research Council, are making a joint effort to formulate a definite plan of experimental attack on the general problem of insulation. The nature of the processes within insulation subjected to electric stress, which result in leakage current, dielectric losses, deterioration, and ultimate break down, is practically unknown. Effort is being made to consult as many as possible of those who are interested in the theory, the manufacture, or the operation of insulation in its various forms. Suggestions of specific problems of insulation whether from a standpoint of theory, manufacture, or operation are, therefore, invited by the joint committees. Communications may be addressed to Dr. J. B. Whitehead, The Johns Hopkins University, Baltimore, Maryland.

PERSONAL MENTION

M. R. Franklin has accepted a position as Electrical Engineer with the Gulf Refining Co., located at Port Arthur, Texas.

Lewis B. Walker has severed his connection with the General Electric Company and is now with the Texas Power Company, Waco, Texas.

Augustus H. Siegfried has resigned as Chief Electrician of Los Angeles, County, California, to enter the consulting engineering field in México.

George I. Wright, until recently employed by the Duluth Edison Electric Company, has accepted a position with the Illinois Central Railroad, Chicago, Ill.

A. N. Johns has resigned from the California Railroad Commission to accept a position as Chief Engineer with the Associated Telephone Company, Long Beach, Calif.

Lloyd N. Robinson, recently chief electrical engineer for the Merced Irrigation District at Merced, Calif., is now electrical engineer for Stone & Webster, Inc., at Seattle, Wash.

Dean W. Taylor, formerly Power Salesman with the Public Service Co. of Northern Illinois, is now Business Engineer for the Wisconsin-Minnesota Light & Power Co., Eau Claire, Wis.

George R. Sullivan has resigned his position with the Kennecott Copper Corporation, Latouche, Alaska, to become Chief Engineer of the power plant at Nacozari, Sonora, Mexico.

Ethan Viall has been appointed as Ohio editor of the *American Machinist*, with headquarters at Cincinnati. Mr. Viall has had an extended connection with this paper on its editorial staff.

Robert B. Morton, until recently Electrical Engineer with Toltz, King & Day, St. Paul, Minn., is now Electric Distribution Engineer with the St. Paul Gas Light Company, St. Paul, Minn.

Calvin J. Adams, for a number of years employed by the General Electric Company, has accepted a position on the consulting engineering staff of the Hudson Coal Company, Scranton, Pa.

Thomas F. Roche, formerly Electrical Instructor, State Trade School, Putnam, Conn., has resigned to accept a position with the B-D Rising Paper Co., as Chief Electrician, North Adams, Mass.

J. R. Werth, formerly Commercial Service Manager of the West Penn Power Company of Pittsburgh, is now with the Oklahoma Gas and Electric Company as Commercial Agent, at Poteau, Okla.

William Baum, President of William Baum & Co., Consulting Industrial Engineers of Milwaukee, has been appointed Vice President of the National Society of Industrial Engineers, in charge of research.

J. K. Leibing has severed his connection with the Great Western Power Co., of California, to take a position in the general engineering laboratories of the General Electric Company at Schenectady, N. Y.

Ben L. Cathey has resigned as Electrical Engineer of the Corporacion Minera de Famatina Chilecito Argentine and is connected with the main office of the Service Dept. of the Westinghouse Electric & Mfg. Co.

William S. Hill has resigned as Electrical Engineer for the Missouri Water Power Co. at Lebanon, Mo., and has accepted a position as General Superintendent of the Grays Harbor Railway and Light Co., Aberdeen, Wash.

G. C. Sutton, until recently electrical engineer for the Panhandle Lumber Co., of Spirit Lake, Idaho, has resigned his position to enter the organization of the General Machinery Co., of Spokane, Wash., as Assistant Manager.

R. A. Lundquist, Chief Electrician of the Equipment Division of the Bureau of Commerce, has returned from a three months' tour of Switzerland, Germany and Great Britain, where he studied market conditions for electrical goods.

F. A. Raymond, for eighteen years inspector and engineer with the National Board of Underwriters, is now connected with the Gamewell Fire Alarm Telegraph Co., at Newton Upper Falls, Mass., as Consulting and Research Engineer.

P. H. Zipf, until recently with the International Nickel Co. in the construction of their new plant at Huntington, W. Va., has entered partnership with E. F. Beckmeyer, The Encon Company, for general engineering practise, Huntington, W. Va.

George A. Hodge, for nine years General Manager of the Empreza Forca e Luz, Aguas e Exgottos, de Ribeirao Preto, Sao Paulo, has resigned his position and moved to Rio de Janeiro, where he is devoting himself to studying light and power concessions in Brazil.

C. E. Skinner, Assistant Director of Engineering of the Westinghouse Electric & Manufacturing Company, has sailed to attend the meeting of the Rating Committee of the International Electro-Technical Commission to be held in Geneva, Switzerland, beginning November 12.

Benjamin G. Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company, has been awarded the Joseph Sullivant medal by the Ohio State University, in recognition of his notable engineering achievements. Mr. Lamme, a graduate in 1888, is the first recipient of this honor.

Paul M. Lincoln for many years electrical engineer with the Westinghouse Co., and recently with the Lincoln Electric Co., and Past-President of the American Institute of Electrical Engineers, has been appointed Director of the School of Electrical Engineering in the College of Engineering, Cornell University.

Eswin S. Obersdorf, formerly connected with the electrical engineering department of The Foundation Company, 120 Liberty St., New York City, has become associated as Electrical Engineer with the firm of G. Drechsler & Co., Inc., 5948 Grand Central Terminal Building, New York City, engaged in general electrical contracting.

William H. Patchell, Consulting Engineer, of London, England, Vice-President of the Institution of Mechanical Engineers and Member also of the Institution of Civil Engineers and the Institution of Electrical Engineers, of Great Britain, was a recent visitor to the United States. On November 24, he was the guest of honor at a luncheon at the Engineers' Club, New York, which was attended by about twenty-five officers of the American national societies of civil, mining, mechanical, and electrical engineers, the United Engineering Society, and the Federated American Engineering Societies. Mr. Patchell gave an interesting account of the developments in the professional engineering societies in England, particularly the recent formation of the Engineering Joint Council, which was referred to in the September Journal; also of the standardization activities of the societies in Great Britain; and he urged the importance of closer cooperation in this and similar work by the societies in this country and abroad. A message of felicitation from those present representing the American societies to their sister professional engineering societies in England, was formulated and forwarded through Mr. Patchell, who sailed from New York on November 25.

Obituary

Frank Warren Smith, General Manager of the Sundh Electric Company of Newark, N. J., and Associate of the A. I. E. E. died suddenly at his home in Westfield, N. J., November, 20th.

Thomas T. Stribling, an Enrolled Student of the A. I. E. E. was killed by electric shock received while at work as an electrician for the Nashville Railway and Light Co., November 9, 1922.

Clyde Pattee, Associate of the A. I. E. E., died on September 17th, at Hillsboro, Oregon, after a illness of three years. His engineering work was with the Pacific Telephone Company and when compelled to resign on account of ill health, he was District Manager at Prosser, Washington.

Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—G. Byberg, 641 Van Buren St., Milwaukee, Wis.

2.—Thomas E. Carey, c/o Tel. Co., 1175 Osage St., Denver, Colo.

3.—Alvaro Daza, Westinghouse International, Royal Bank of Canada Bldg., Havana, Cuba.

4.—W. S. Guilford, Box 1075, Capetown, S. Africa.

5.—Tadashi Iida, 400 Wilson St., Joliet, Ill.

6.—Robert W. Merritt, 845 S. Gramercy Pl., Los Angeles, Calif.

7.—Clifford E. Olaison, 3322 Columbus Ave., Minneapolis, Minn.

8.—Thomas H. Parker, 1839 Tulare St., Fresno, Calif.

9.—Geo. B. Dodgers, 30 E. 21st St., New York, N. Y.

10.—Robert C. Scott, Box 464, Dundas, Ont., Can.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give nformation concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (OCT. 1-31, 1922)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

WELDING ENCYCLOPEDIA.

By L. B. Mackenzie and H. S. Card. Second edition. Chicago, Welding Engineer Publishing Co., 1922. 388 pp., illus. tables, charts, 9 x 6 in., fabrikoid. $5.00.

A reference book on the theory, practise and application of the four processes for autogenous welding. The first half of the book is a dictionary of the words, terms and trade names used in the industry. Included in this are instructions for the common types of repair and production work, descriptions of tests, specifications for rods and wires, and descriptions of the application of welding in various industries. Following the dictionary are separate chapters on the four processes for welding giving detailed descriptions of each and instructions for its use. Chapters on boilers, tank, pipe and rail joint welding are then given, followed by a section on the regulations of federal and state authorities, and insurance companies, and a chapter on the heat treatment of steel. A collection of charts and tables and a catalog section are also provided.

ESSAIS DE SOUDURES AUTOGENE ET ELECTRIQUE DE PIECES DE CHAUDIERES.

By E. Hoehn. Paris, Ch. Bèranger, 1922. 78 pp., illus., diagrs., 9 x 6 in., paper. 4 fr.

This report gives the results of an extensive series of tests of autogenous and electric welds as applied to boiler construction, carried out in 1921 by the Association Suisse de Propriètaires de Chaudières à Vapeur. The points investigated included the welding of flanges to tubes and boiler shells, the welding of plates at right angles, tensile tests of different forms of welds, the influence of skin on welds, the quasi-arc electric process and the strength of welded tanks.

BROWN'S DIRECTORY OF AMERICAN GAS COMPANIES AND GAS ENGINEERING AND APPLIANCE CATALOGUE.

1922. N. Y., Robbins Publishing Co., 1922. 966 pp., illus., 12 x 9 in., cloth. $10.00.

The book is divided into two sections. Section one is a catalog of gas plant equipment, which contains an alphabetical index of the firms represented, a classified index to their products and condensed catalogs describing them. A catalog of books on the gas industry is included.

The second section is a directory of gas companies. It contains an index of the cities and towns supplied with gas, statistics of the gas companies of North America and of holding and operating companies, financial reports of holding and operating companies, the high and low prices of gas securities, a list of public service commissions and an alphabetical list of the members of the leading gas associations.

ADVANCED LABORATORY PRACTISE IN ELECTRICITY AND MAGNETISM.

By Earle Melvin Terry. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1922. 261 pp., illus., diagrs., 9 x 6 in., cloth. $3.00.

For those students who have only one year for the study of electricity and magnetism in addition to the work covered in an elementary course in general physics. In addition to the usual work in electrical measurements, the book includes a study of the discharge of electricity through gases, radio activity and thermionics. The book covers the work given to third year students of electrical engineering at the University of Wisconsin.

AUTOMOTIVE REPAIR. v. 2, for Electrical Service Men.

By J. C. Wright, N. Y., John Wiley & Sons; Lond., Chapman & Hall, 1922. 417 pp., illus., diagrs., 9 x 6 in., cloth. $3.00.

The second volume of this comprehensive manual for repairmen treats of the electrical equipment of automobiles. It presents carefully detailed instructions for fifty-six electrical repair jobs, covering the derangements that occur most frequently. These are fully illustrated with drawings and photographs. In addition an account of electrical theory is given, sufficient for a thorough understanding of the functions of the electrical equipment of automotive vehicles.

INTRODUCTION TO THE CHEMISTRY OF RADIO-ACTIVE SUBSTANCES.

By A. S. Russell. Toronto, Macmillan Company of Canada' 1922. 173 pp., tables, charts, 8 x 5 in., boards. $2.00. (Gift of Macmillan Co., N. Y.)

A short account of the chief facts concerning the chemistry of radio-active substances at present known, intended for students of the subject. The author states it to be, as far as he is aware, the only book in English which is reasonably up-to-date.

INVENTION OF THE TRACK CIRCUIT.

N. Y., Signal Section, American Railway Association, 1922. 113 pp., illus., port., 10 x 7 in., paper.

In honor of the fiftieth anniversary of the invention of the track circuit by Dr. William Robinson of Brooklyn, the present volume has been prepared by a special committee of the Signal Section of the American Railway Association. Section one gives a history of the invention, Robinson's patent, and his own description of the invention. Section two is a memorial to W. A. Baldwin, formerly General Superintendent of the Pennsylvania Railroad, who first installed automatic block signals controlled by track circuits. Section three describes the track circuit as used today. Section four treats of European usage.

PATENT ESSENTIALS.

By John F. Robb. N. Y. & Lond., Funk & Wagnalls Co., 1922. 436 pp., plates, charts, 9 x 6 in., cloth. $5.00.

Treats of the nature of patents, the mechanism of their procurement, claim drafting, conduct of patent cases and special proceedings, including forms. Is the work of an experienced patent attorney, but is intended for laymen who wish to under-

stand the essentials of law and practise before the Patent office, rather than for experts.

VAN NOSTRAND'S CHEMICAL ANNUAL.

Ed. by John C. Olsen. Fifth issue, 1922. N. Y., D. Van Nostrand, 1922. 900 pp., port., charts, tables, 7 x 5 in., fabrikoid. $4.00.

This book is intended to supply, in convenient form, the tables and numerical data most frequently required by chemists. The present fifth edition has been carefully revised and enlarged. The literature has been searched for new data on the compounds listed in the book and corrections have been made when necessary. A considerable number of new compounds has been included. About forty-six new tables have been added.

THOMAS' REGISTER OF AMERICAN MANUFACTURERS. 13th Year, 1922.

N. Y., Thomas Publishing Co., 1922. 4500 pp., 9 x 12 in., cloth. $15.00.

The Register answers immediately the three usual questions that arise in every purchasing department. It contains lists of the makers of over 70,000 articles and gives the capital rating and address of each. It also furnishes a directory of manufacturers, giving their addresses, lines, branches, etc. Section three lists over 50,000 trade named articles with the names of their manufacturers. For many years a standard directory, this edition has been carefully revised to the time of issue.

Past Section and Branch Meetings

PAST SECTION MEETINGS

Akron.—October 24, 1922. Subject: "The Portable Oscillograph." Speaker: Mr. J. W. Legg, designer of the instrument under discussion. Attendance 65.

Baltimore.—October 20, 1922. Subject: "The Trackless Trolley." Speaker: Mr. H. B. Flowers, General Manager of the United Railways & Electric Co. Attendance 53.

Cincinnati.—October 26, 1922. Subject: "Problems of Maintaining Continuous Service in an Edison System." Speaker: Mr. F. D. Wyatt, Electrical Engineer of the Union Gas & Electric Co. Discussion followed by Messrs. Wilson, Willey and Culver. Attendance 70.

Cleveland.—October 19, 1922. Program of the year outlined. It was decided that the Section affiliate with the other technical societies of Cleveland. There was a talk by Mr. Osborne, Transmission Engineer of the American Telephone and Telegraph Co., on the factors involved while carrying on telephonic conversation between Catalina Island and Havana, Cuba. Slides and moving pictures illustrated the talk. Discussion followed by Messrs. Potter, Harden, Kobroch, Williams, Kives. Attendance 250.

Columbus.—October 19, 1922. Subject: "Railway Electrification and Its Relation to Management," by Mr. H. L. Kirker. The paper was discussed by Messrs. Fitz, Schwendt, Norton, Ruggles. Attendance 56.

Connecticut.—October 27, 1922. Joint meeting with the Yale University Branch. See notice under Past Branch Meetings.

November 23, 1922. Joint meeting with Waterbury Branch, A. S. M. E. Subject: "Waterbury's Power Supply." 1. "Its Development," by Mr. Irvin W. Day. 2. "Its Distribution to the Consumer," by Mr. Alexander J. Campbell. 3. "Electrical Problems Involved," by Mr. Paul Spencer, and 4. "Valuation of Water Power to the Situation," by Mr. Rollin Norris.

Denver.—October 20, 1922. Committees appointed. Mr. E. B. Curry, representative of the Mechanical Dept. of the Chicago, Milwaukee and St. Paul R. R. Co., delivered an interesting talk on the construction and operation of the electrification on the main railway lines from eastern Montana to the Pacific Coast. The talk was illustrated by lantern slides and motion pictures. An interesting discussion followed. Attendance 58.

Detroit-Ann Arbor.—October 13, 1922. The Mayor of Detroit requested a member of the Institute to be selected to act on a commission to investigate rapid transit. Mr. Kitteredge, Chief Engineer of the Michigan State Telephone Company, assisted by Mr. E. L. Beale, gave the reasons and general scheme for changing to machine switching in the one exchange in Detroit. Attendance 116.

November 10, 1922. Mr. A. C. Marshall, Vice President of the Detroit Edison Co. gave an interesting outline on financing of public utilities. Mr. Berry of the Detroit Edison Co., outlined the Connors Creek Power House and gave instructions regarding the inspection trip which followed. Attendance 250.

Erie.—October 17, 1922. A joint meeting of the Engineer's Society of Northwestern Pa., the Erie sections of the A. I. E. E. and A. S. M. E. was held to pass on the matter of affiliation of the Engineering Societies in Erie. A talk on "The Human Relation," by Mr. C. J. Carew of the Travellers Insurance, followed. Attendance 10.

October 24, 1922. Subject: "The Lighting of Our Homes," by Mr. A. H. Richardson, of the Publication Dept. A moving picture film, furnished by the General Electric Co., was shown. Attendance 25.

Fort Wayne.—October 26, 1922. After a business meeting and talk by Mr. John M. Frase on the advantages of Institute membership, there was a talk by Mr. S. P. Anspach, Manager of the Edison Lamp Works, who spoke on the manufacture and production of lamps at the local works from 1910 to the present time. Attendance 115.

Indianapolis-Lafayette.—October 27, 1922. Subject: "Industrial Control Devices as Applied to Alternating Current Motors in Industrial Fields." Speaker: Mr. E. B. Smith. A motion picture "Beyond the Microscope" was shown. Attendance 63.

Minnesota.—October 30. Dinner. Attendance 33.

New York Section:—The second meeting of the administrative year 1922-23 of the N. Y. Section of the Institute was held in the Auditorium, Engineering Societies Building, 33 West 39th St., New York on the evening of Friday, Nov. 24, 1922 at 8 p. m. with an attendance of about 150. The paper for the evening "Electrical Engineer on Shipboard" was presented by George A. Pierce, Jr., Chief Electrical Engineer of Wm. Cramp & Sons Ship and Engine Building Co. Mr. Pierce's paper constituted the first public presentation of the plea for recognition by the Federal Steamboat Inspection Service and also by owners and operators of the absolute necessity for having competent electrical engineers on the modern ship with its extensive and extremely complicated electrical equipment. At present the Steamboat Inspection Service, making the rules governing the operation of vessels, does not recognize the existence of the electrical engineer, he can not be an officer, but only have a rating of an oiler. Mr. Pierce stated that on certain of the new motorships lately commissioned it had been found necessary for the builders to make up the difference between an oilers pay of $60.00 per month and that necessary to obtain a competent electrical man. It was also necessary to appeal to the Captain to obtain permission for the electrical engineer to mess with the officers. Steps must be taken the speaker concluded to give

marine electrical engineers a definite rating, a salary commensurate with the responsibility imposed and the type of trained man required. Among those who discussed the subject were Captain H. M. Seeley, Supervising Inspector of the Steamboat Inspection Service, J. F. Clinton, electrical engineer with the U. S. Shipping Board, Lieut. Salberg, Chief Engineer Oleson, W. E. Thau of the Westinghouse Elec. & Mfg. Co. Mr. Clinton particularly, cited cases of both efficiency and non-efficiency in the handling of ships coming under his jurisdiction and of the results obtained and the troubles and disasters which might well have resulted on those boats where incompetent men were handling the electrical equipment.

Philadelphia.—November 13, 1922. Subject: "The Trackless Trolley." Speaker: Mr. J. A. Queeney, of the General Electric Company, Schenectady. Mr. J. A. Collins, Chief Engineer of the Mitten-Traylor Co., described in detail the gas propelled bus. Discussion of papers by Messrs. Stock and Flower. Attendance 131.

Pittsburgh.—October 10, 1922. Subject: "Surges in Power Systems." Speaker: Dr. J. Slepian. Interesting discussion followed. Attendance 254.

Pittsfield.—October 19, 1922. Subject: "Modern Trend in Electrical Development." Speaker: Dr. C. P. Steinmetz. Attendance 300.

November 9, 1922. Talk by Mr. W. J. Humphreys of the U. S. Weather Bureau. Attendance 400.

Rochester.—October 27, 1922. Mr. W. S. Bouldt, Manager of the New York Office of the Sangamo Electric Co., described and presented a three-reel motion picture "The Story of an Electric Meter." Attendance 75.

Schenectady.—Subject: "The General Electric Company's World Position." Speaker: Mr. Gerard Swope. Attendance 400.

Seattle.—September 29, 1922. Annual dinner. Business meeting and election of officers. Attendance 46.

October 25, 1922. Inspection trip to the Melrose Automatic Substation of the Pacific Telephone and Telegraph Co. Attendance 91.

Springfield, Mass.—November 3, 1922. Business meeting and talk by Dr. M. J. Kelley, Electrical Engineer, Western Electric Co., on "The Theory of Vacuum Tubes." There were moving pictures and stereopticon views. Attendance 99.

Toledo.—October 26, 1922. Subject: "The Development of the Alternating Current Elevator." Speaker: Mr. E. B. Thurston. Discussion followed. Attendance 24.

Toronto.—October 13, 1922. Social Meeting. Attendance 117.

November 3, 1922. Subject: "Mechanical Stresses in Bus Bars Under Short Circuit Conditions." Speaker: Mr. C. H. Van Asperin. A discussion by Mr. H. B. Dwight was read and slides were shown. Attendance 83.

November 10, 1922. Subject: "Electrons." Speaker: Dr. J. C. McLennan. The address was illustrated by slides and experiments. Attendance 180.

Urbana.—Subject: "Recent Power Plant Development." Speaker: Mr. E. B. Paine. Attendance 60.

Utah.—October 25, 1922. Business meeting and buffet luncheon. Attendance 31.

Worcester.—October 19, 1922. Inspection of Cable Works, South Works, American Steel & Wire Co., in afternoon. Evening meeting. Subject: "Manufacture of Electric Wire Cables." Speaker: Mr. C. F. Hood. Attendance 48.

PAST BRANCH MEETINGS

Alabama Polytechnic Institute.—October 7, 1922. Subject: "Queenston-Chippewa Power Development." Speaker: Miss Maria Whitson. Attendance 17.

University of Arizona.—October 4, 1922. Talk by the Chairman, Mr. McDonald, on the purpose and aims of the Institute, especially with reference to students. Attendance 19.

University of Arkansas.—October 2, 1922. Election of officers. Attendance 13.

October 17, 1922. Subject: "Testing High Tension Insulators." Speaker: Mr. B. R. Askew. Attendance 10.

October 31, 1922. Subject: "A Million Volt Testing Set," by Mr. J. W. Booker, and "Advancement of Radio Work," by Mr. J. E. Hutcheson. Attendance 12.

Armour Institute of Technology.—October 19, 1922. Subjects: "One-Man Care in Large Cities," by Mr. J. S. Farrell, and "Substations of the Chicago, Milwaukee and St. Paul Railway," by Mr. J. D. Hayes. Attendance 33.

November 2, 1922. Subject: "The Practical Side of Engineering." Speaker: Mr. A. F. Hibbler. Attendance 42.

Brooklyn Polytechnic Institute.—October 20, 1922. Subjects: "History of Hydroelectric Power Plants," by Prof. H. Hammond, and "Gaseous Telephone Transmitters," by Mr. F. Nimmcke. Attendance 80.

Bucknell University.—November 1, 1922. First meeting of year. Election of officers. Prof. Rhodes explained the purpose of the organization. Attendance 26.

University of California.—October 4, 1922. Business meeting and enrollment of 54 new members. Attendance 81.

October 21, 1922. Inspection trip on the Diesel-electric ferry "Golden Gate." Attendance 98.

November 1, 1922. Subject: "The Eldorado Development of the Western States Gas and Electric Co." Speaker: Mr. Thos. James. Attendance 63.

Case School of Applied Science.—October 13, 1922. Election of officers. Attendance 30.

University of Cincinnati.—September 28, 1922. Subject: "What Is New in Civilization." Speaker: Prof. A. M. Wilson. Attendance 80.

October 12, 1922. Repetition of talk of September 28, before another section. Attendance 75.

October 19, 1922. Subject: "Some Things Done at the Convention of Electrical Jobbers and Dealers in Cincinnati." Speaker: Mr. Curran. Attendance 86.

October 26, 1922. Subject: "Possibilities in the Field of Electrical Engineering." Speaker: Mr. S. D. Heed. Attendance 86.

November 2, 1922. Subject: "Electrification of Railways." Speaker: Mr. W. F. Dunkle. Attendance 55.

University of Colorado.—October 5, 1922. Election of officers. Talks on the aims and benefits of the Institute were given by Dean Evans, Professors DuVall, Coover, Lindsay and Mr. Easton. Attendance 75.

Cooper Union.—November 11, 1922. Subject: "Protective Devices for High Tension Equipment." Speaker: Mr. George W. Warnecke, and "Thermo-Electric and Resistance Pyrometers," by Mr. Charles F. Schmid. Attendance 39.

University of Kansas.—September 28, 1922. First meeting of year. Election of officers. Attendance 83.

October 12, 1922. Subject: "The History and Development of the Telephone." Speaker: Mr. C. J. Larson. Attendance 62.

Kansas State College.—October 9, 1922. Subject: "The Advantages of Belonging to the A. I. E. E." Speaker: Mr. Lester Means. Attendance 64.

October 23, 1922. Subject: "My Summer's Work with the Bell Telephone." Speaker: Mr. George Myers. Attendance 68.

Lafayette College.—September 23, 1922. Election of officers. Attendance 19.

September 30, 1922. Subjects: "The National Conference of the A. I. E. E." and "Queenston Project of Power Development and Its Problems," by Mr. Mercer. Attendance 20.

October 7, 1922. Subject: "The Question of Illumination," illustrated lecture, by Prof. King. Attendance 21.

Lehigh University.—October 19, 1922. Subject: "What the Present Day Expects of the Electrical Engineer." Speaker: Mr. Walter C. Wagner. Attendance 80.

Lewis Institute.—November 8, 1922. Election of officers and outlining of work of Branch. Attendance 16.

Marquette University.—October 12, 1922. Smoker and short speeches by faculty members on the purpose and value of the Branch. Attendance 42.

Michigan Agricultural College.—October 24, 1922. Subject: "The Kellogg Corn Flake Co.," by Dr. A. W. Bosworth, "The Human System and Its Needs," by Mr. J. L. Kellogg. Attendance 78.

Engineering School of Milwaukee.—October 27, 1922. Subject: "Radio Apparatus Development." Radio concert. Attendance 42.

University of Missouri.—October 3, 1922. Election of officers. Talk by Prof. A. C. Lanier on the "Aims and Ideals of the A. I. E. E." Attendance 102.

October 18, 1922. Messrs. L. E. Lockwood, P. W. McCormick, Paul Thornton, R. L. Linney and R. S. Bennington spoke on their experiences in summer employment. Attendance 40.

Montana State College.—October 10, 1922. Program for the year was outlined and committees appointed. Attendance 116.

University of Nebraska.—October 18, 1922. Subject under discussion was radio. Talks by Mr. B. S. Ellsworth and Mr. J. A. Brooks. Attendance 30.

University of North Carolina.—October 20, 1922. Business meeting. Appointment of officers and committeemen. Attendance 27.

November 2, 1922. Fall smoker. Attendance 68.

University of North Dakota.—October 23, 1922. Business meeting. Attendance 15.

November 6, 1922. Subject: "The Theory of the Vacuum Tube." Speaker: Mr. E. J. Lamb. Attendance 11.

University of Notre Dame.—October 23, 1922. Subject: "The Power House System in Philadelphia." Speaker: Mr. M. Donato. Attendance 50.

November 9, 1922. A three-reel film "The Story of an Electric Motor" was shown. Attendance 62.

Ohio Northern University.—October 26, 1922. Short talks by Dean Alden and Prof. Carpenter and Fairchild. Social meeting followed. Attendance 30.

Ohio State University.—October 26, 1922. Smoker. Short talks by faculty members on advantages attendant upon membership in the A. I. E. E. Attendance 125.

Oklahoma University.—November 9, 1922. Subject: "Electric Railways." Speaker: Mr. Bourke. Short talks about the A. I. E. E. by Prof. Tappan and Prof. O. W. Walter. Attendance 22.

Oregon State Agricultural School.—October 18, 1922. Subject: "The Value of the Institute to the Student of Electrical Engineering." Speaker: Prof. R. H. Dearborn. Attendance 36.

Pennsylvania State College.—October 4, 1922. Subject: "Electrical Engineering Society Activities and Advantages of Attending the Meetings Regularly." Speaker: Prof. E. B. Stavely. Attendance 52.

October 11, 1922. Social meeting and short talks by members of the faculty. Attendance 200.

Purdue University.—October 24, 1922. Subject: "Training Men for Responsible Positions." Speaker: R. J. Burton. Attendance 115.

Rutgers.—October 12, 1922. Talks by Dean Rockwell, Profs. Lendall Heck, Thomson and Mr. Creager. Attendance 125.

October 26, 1922. Two General Electric films were shown "Revelations of the X-Ray" and "Five Bog Deeds." Attendance 30.

University of Southern California.—October 10, 1922. Subject: "The National and Local Organizations of the A. I. E. E." Speaker: Mr. Stauffacher. Attendance 12.

November 8, 1922. Subject: "The Theory of the Electron and Electricity." Speaker: Mr. Ivan Summers. Attendance 22.

Swarthmore College.—September 29, 1922. Business meeting; election of officers. Talk by Dr. L. Fussell on his summer work with the Bell Telephone Co. Attendance 11.

October 20, 1922. Subject: "The New York-Chicago Cable." Speaker: Walter Schulz. Attendance 11.

October 27, 1922. Subject: "Power Factor." Speaker: Mr. Gaskill.

November 3, 1922. Subject: "The Distribution of Power by the General Electric Company." Speaker: Mr. Stephen Bunting. Attendance 11.

Syracuse University.—October 12, 1922. Subject: "The Manufacture of Tungsten Filament Lamps," by Mr. Donald L. Baxter, and "Pyrometers," by Mr. Ephriam Port. Attendance 23.

October 26, 1922. Subject: "Electric Steel Furnaces," by Mr. Paul A. Klinkert, and "Buffalo General Electric Plant," by Mr. John Channel. Attendance 20.

Agricultural and Mechanical College of Texas.—October 9, 1922. Talk by Dr. F. C. Bolton on the aims of the Institute. Attendance 60.

October 16, 1922. Subject: "Railway Crossing Safety Signals," by Mr. W. S. Miers Attendance 80.

Virginia Polytechnic Institute.—October 19, 1922. Election of officers. Attendance 41.

University of Virginia.—October 12, 1922. Talk by Prof. W. S. Rodman on the A. I. E. E. student branches. Talk by Mr. T. R. Bunting on "The Western Electric Loud Speaking Apparatus," followed by a radio concert. Attendance 22.

University of Washington.—Election of officers. Subject: "The Opportunities for Young Engineers in the Telephone Business." Speaker: Mr. J. V. Cousins. Attendance 26.

West Virginia University.—October 23, 1922. Subjects: "Engineering Students and Engineering Courses," by Mr. C. Ray Lame, "Use of Carbon Brushes for Motors," by Mr. A. T. Richards, "Wave Motion for the Production of Distant Effects," by Mr. Chas. Snyder, "Need for a New System of Electromagnetic Forces," by Mr. C. B. Hutson, "Development of an Electron Tube Amplifier Which Uses 60 Cycle A. C. to Supply Power for Filament and Plate," by Mr. L. D. Fahler, "Automotive Generation," by Dr. W. D. Stump, "Short Wave Lengths in Wireless," by Mr. C. D. Ernest, "The First Central Station," by Mr. Ira O. Myers, "Electron Tubes," by Mr. R. Bayers, and "Electric Deposition of Iron," by Mr. N. Barone. Attendance 31.

November 6, 1922. Subjects: "High Melting Point Solder for Brushes," by Mr. C. E. Pitsenberger, "Utilization of Surplus Flood Water to Suppress Backwater Upon Water Power Developments," by Mr. C. E. Hutchenson, "Porcelain Insulators," by Mr. O. A. Brown, "Life History and Development of Electric Industry Made by George Westinghouse," by Mr. T. N. Farman, "Trained Thought Vs. Gathering Information," by Mr. R. K. Parks, "Railway Electrification," by Messrs. Pierie Hill and I. A. Pitsenberger, "Electric Trucks," by Mr. R. Rosier, "Life of Alexander Bell," by G. C. Pugh, "The Power Factor, Its Cause and Remedy," by Mr. W. G. Steele. Attendance 28.

University of Wisconsin.—October 25, 1922. Business meeting and talk by Mr. Malcom Hanson on "Recent Radio Developments." Attendance 24.

Yale University.—October 27, 1922. Address by Dr. Jewett. Subject: "Some Recent Developments in Telephony and Telegraphy." Speaker: Mr. E. B. Craft. Attendance 2000.

Employment Service Bulletin

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements will be publishedwithout charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL ***should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,*** *the employment clearing house of the National Societies of Civil, Mechanical, Mining and Electrical Engineers.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case ***and forwarded to EMPLOYMENT SERVICE,*** *as above.*

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

OPPORTUNITIES

ELECTRICAL ENGINEER for remote control and substation design. Must be thoroughly familiar with use of relays. Must be electrical engineering graduate, under 45 years of age. Full details of education, experience, salary and time available should be given in first letter. Location, Pa. V-43.

DRAFTSMAN for checking electrical drawings' wiring diagrams, etc. Must be electrical engineering graduate, under 45 years of age. Full details of education, experience, salary and time available should be given in first letter. Location, Pa. V-44.

ELECTRICAL DRAFTSMAN who can be generally useful on drafting board in connection with station layout work and re-vamping of existing work. Location, New York State. V-325.

EXPERIENCED STEAM HEATING AND STEAM SPECIALTY SALESMEN to represent long established vacuum and vapor heating manufacturer. Application by letter giving full experience, territory desired, lines carried, etc. Commission basis. Some good territory open. Headquarters, Illinois. V-382.

PARTNER to start contracting business in electrical equipment of buildings and mechanical equipment of factories. Requires both investment (about $5000) and ability to obtain and close contracts. Application by letter. Salary, division of profits. Location, New York City. V-1594.

BRANCH MANAGER, capable of conducting electrical supply and construction business of from fifty to one hundred thousand per year. Preferably one who has had experience in this line and has marked selling and executive ability. Application by letter. Salary not stated. Location, New York State. V-1597.

ELECTRICAL ENGINEER familiar with utility accounting who can qualify as a cost and efficiency analyst, in connection with gas and electric operation and construction. Position offers opportunities for advancement with a rapidly growing company and salary would depend upon ability. Application by letter. Location, New York State. V-1724.

TECHNICAL GRADUATE with considerable designing experience. Major work mechanical nature on stationary structures involving practically no moving parts. Electrical knowledge and knowledge of transformer construction advantageous; but fundamental mechanical knowledge most essential. Experience in tank construction and in structures involving rolled plates and shapes desirable. Electric and autogenous welding is done on work involved. Experience in standardizing essential. Main functions will be to gradually polish up desirable standards and assist in selling the idea of sticking to these standards. Application by letter. Salary not stated. Location, Pa. V-1761.

ELECTRICAL MANUFACTURING PLANT offers apprenticeship course for boys 13-17 who possess mathematical ability. Will be given courses in calculus, mechanical and electrical theory, chemical shop work, etc. Half time will be spent in commercial work which will be paid for. Application by letter. Salary not stated. Location, Mass. V-1774.

ELECTRICAL DRAFTSMAN, experienced in power house substation and switchboard design and layout. Application by letter stating education, experience and salary expected. Send photograph if possible. Location, Ill. V-1829.

HIGH CLASS ELECTRICAL SALES REPRESENTATIVES for reliable concern manufacturing carbon graphite, electro-graphitic and metallic brushes for motors and generators, also general lines of carbon specialties. Exclusive rights given to each of territorys on liberal straight commission sales porposition. Specify in detail past engineering and sales experience. Territories Chicago vicinity, St. Louis, Birmingham, Washington, D. C., Detroit. Headquarters, N. Y. V-2184.

SALES ENGINEERS. Should be naturally good order closers, able to figure power required. One man familiar with compressed air, small electric motors and automatic control systems; one for small high pressure water pumps for suburban and public building trades, architects, etc.; one for exclusive line of short belt drive idler systems. Automobile necessary. Application by letter. Headquarters, Los Angeles, Calif. V-2444.

SALES EXECUTIVE for well established firm of engineers and constructors in New York. Must be a man of character and standing, with a wide acquaintance among business men and a talent and personality for sales. Assured future for right man. Application by letter giving full information. Salary not stated. Location, New York City. V-2510.

ENGINEERING SALESMAN. Good opportunity for young electrical engineering graduate to establish with a large electrical manufacturing concern as a sales engineer. Application by letter stating important particulars in first letter. Salary not stated. Location, Central. V-2526.

ENGINEER who has had actual d-c. design experience and who is young enough to be able and willing to adapt himself to the company's method of designing. Should have at least two or three years of actual experience in designing interpole machines. Application by letter. Salary not stated. Location, New Jersey. V-2534.

TRAVELLING SALESMEN to demonstrate, sell, install and operate new radiophone loud speaker and electrical phonograph attachments. Must have combination of experience including successful sales record in and intimate knowledge of radiophones. Graduate electrical engineer preferred. Highest character reference required. Application by letter stating age, experience and salary desired. If convenient, enclose photographs and names of four references. Headquarters, New York City. V-2720.

YOUNG MEN, high grade to travel through manufacturing and industrial districts to install, inspect and test electrical instrument and temperature controlling equipment; special consideration will be given to applicants who have had experience in handling instruments, meters, gages, recorders, controllers, etc., educated man preferred; unusual chance for promotion. Application by letter stating experience, education, age and salary desired. Headquarters, New York City. V-2721.

PATENT ATTORNEY (Young Man). Duties to follow up cases in office. The preparation and presentation of cases handled by an outside attorney. Application by letter. Salary not stated. Location, New York City. V-2723.

ASSISTANT TO DRYER ENGINEER. Must have construction experience, drafting and dryer. Application by letter. Location, N. Y. C. V-2728.

RECENT GRADUATE who has just obtained degree or who has possibly had a year or so experience. Will be placed in Research Dept. and, after necessary instructions and training, will be assigned work of running down certain developments and experimental work. Should be interested primarily in steam power plants. Application by letter. Salary not stated. Location, Philadelphia, Pa. V-2735.

ELECTRICAL ENGINEER & CHEMICAL ENGINEER. A graduate within last five years. Application in person. Location, New Jersey. V-2738.

ELECTRICAL ENGINEER, technical graduate with eight to ten years' experience. To supervise design of substations, generating stations and transmission lines for power company with something over 150,000 kw. and several hundred miles of transmission on its system. Application by letter. Salary not stated. Location, New York State. V-2739.

CHIEF ENGINEER, experienced in machine tool design, by concern in central Indiana. Desire a man with executive ability, who is able to successfully combine technical knowledge with practical ideas. In reply give full particulars including experience and salary desired. V-2749.

DISTRICT MANAGER for high temperature heating material. Applicant must be familiar with Pittsburgh and surrounding section. Application by letter. Salary not stated. Headquarters, New York City. V-2757.

YOUNG MECHANICAL ENGINEER to assist on fan tests and working up of data. Power plant experience desirable. Application by letter. Location, New York State. V-2759.

SALES ENGINEER for sub-agencies in the following district:—Southern Ohio, Kentucky and Western West Virginia. Company manufactures road machinery, contractors equipment, etc. All engineering supervision in drawings, specifications and publicity furnished. Application by letter. Liberal Commission. Headquarters, Ohio. V-2761.

ELECTRICAL ENGINEER, preferably young man with imagination, able to see engineering problems in their fundamentals. Able to make proper tests for determining kind of power to apply to a machine and draw proper conclusions. Much traveling involved, and must be able to meet people successfully. Permanent position and chance for advancement. Application by letter giving full information. Salary not stated. Location, Ohio. V-2762.

ELECTRICAL MANUFACTURING GRADUATE for operating department to assist in making estimates of small extension, transformer installations and service jobs and look after certain department records and make investigations of problems arising in operation of electrical distribution system. Preferably should have had at least one to two years' practical experience. Application by letter. $150 per month. Location, W. Va. V-2765.

RECENT GRADUATES (2) willing to learn power specialty business, spending two months in each of six shops for training purposes. Application by letter only. Salary while training. Advancement depends on progress. Headquarters, N. Y. C. V-2772.

FACTORY MANAGER having extended experience with production methods, modern manufacture of electric motors and generators and shop management. Application by letter stating age, education, past experience and salary expected. Interview arranged later. Location, Middle West. V-2780.

INSPECTOR, competent technical man with experience in manufacturing departments inspecting details of electrical power apparatus. Application by letter stating briefly past experience, age, education and salary. Location, Ohio. V-2781.

ENGINEER to manufacture flexible metal tubing. Must have had experience in this line of work; or interlocking metal tubing. Application in person. Salary not stated. Location, N. Y. C. V-2801.

SALES ENGINEER to sell industrial conveyors. Must have well balanced combination of engineering, analytical and selling ability. Will be called upon to faciliate, expedite and economize movement and transportation of materials through and out of processes of production in all kinds of industrial plants and handle all sorts of things by means of conveyors in different mercantile and commercial establishments. Must be able to thoroughly analyze processes and economical factors involved and have sufficient ability to instill confidence, inspire respect and carry conviction. Application by letter. Salary not stated. Location, New York State. V-2802.

EXPERIENCED TESTING ENGINEER familiar with a-c. and d-c. motors and other electric power house apparatus. Application by letter. Salary not stated. Location, N. Y. V-2803.

SALESMEN for outside work. Columbia men preferred. Sales experience with construction and industrial plants. Application in person. Salary not stated. Location, N Y. C. V-2813.

YOUNG TECHNICAL GRADUATE in electrical engineering concern. All drafting work in connection with construction of high-tension transmission lines, power houses and sub-station. Application by letter. Salary will depend somewhat upon experience of applicant. Location, New York State. V-2815.

SALESMAN AND SALES M G ER. Co. makes "Quick Fire" which is a preparation to be added to motor gasoline to prevent formation of carbon. Work is selling to garage-keepers and repair shops. Application in person. Commission basis. Location, New York and East. V-2819.

SUPERVISOR of Installation of heating, ventilating and power plant equipment. Should be thoroughly experienced in this work. Application by letter. Salary not stated. Location, N. Y. C. V-2820.

ESTIMATOR AND LAYOUT MAN on heating, ventilating and power plant equipment. Must be qualified to take responsible charge of this work. Application by letter. Salary not stated. Location, N. Y. C. V-2821.

SALESMAN for soliciting contracts. Man will be assisted by G. E. man in soliciting lighting l Young man preferred. Application by letter. Location, N. Y. C. V-2823.

SYRACUSE AND ALBANY DISTRICT REPRESENTATIVES of fast growing company, specializing in complete accountancy service for medium and small businesses. Requirements—successful sales experience among business executives; general knowledge and appreciation of accountancy principles. Technical education preferred. Straight commission paid monthly on total business in force. Income small at first, but builds up rapidly. Application by letter giving complete history. Headquarters, New York State. V-2826.

YOUNG ELECTRICAL ENGINEER who has taken the G. E. or Westinghouse training course and has since had 2 years designing experience along electrical designs to act as assistant to chief designer. Application by letter. Salary not stated. Location, Ohio. V-2828.

DESIGNER for hydraulic machinery for large concern in the East. Only A-1 with experience need apply. Permanent position with advancing possibilities. Application by letter stating age, education and experience. Salary not stated. V-2839.

SUPERINTENDENT of bag factories located in St. Louis. Want to secure man that has had technical training, and one that has had some experience in production work and who hopes to specialize in manufacturing and human control. Application by letter. Salary not stated. V-2840.

HEATING AND VENTILATING ENGINEER with 5-6 years experience. Must possess personality and ability to develop. Permanent position. Able to write specifications. Application by letter. Location, N. Y. C. V-2844.

ENGINEER with thorough knowledge of pipe working and various pipe manufacturers to take charge of fabricating shop. Must possess executive and sales ability and experience. About 35 years of age. Application by letter. Salary not stated. Location, New York City. V-2845.

DRAFTSMAN, COMPUTER. STENOGRAPHER. Young man of limited engineering experience; able to take rapid technical dictation; do neat typing; handle slide rule, adding machines, Monroe computing machines, etc.; to do lettering and some drafting and tracing. Preferably unmarried and able to shift temporarily his location during progress of work. Some knowledge of simple bookkeeping desirable. Opportunity to learn considerable about public utility engineering business. Application by letter. Salary not stated. Location, New York City. V-2847.

ASSISTANT ENGINEER. Young man with more or less experience in appraisal work and design of hydraulic and steam plants of small moderate size. Should be college graduate, wi broad knowledge of engineering principles, some training in electrical engineering and ability to do simplest of civil and mechanical engineering operations. Preferably unmarried or able to shift his location temporarily during work on various projects. Some knowledge of telephone practise would be an aid. Application by letter. Salary not stated. Location, New York City. V-2848.

ENGINEER in charge of power, repair and construction. Technical graduate in mechanical or electrical engineering. Age 30-35. Experienced in modern boiler and engine practise. Theoretical and practical knowledge of generation, distribution and utilization of electrical energy. Capable of handling small force of mechanics, carpenters, bricklayers, etc. Application by letter. Salary $275 per month. Location, Illinois. V-2849.

ENGINEER holding Commercial Radio Operator's License, Second Class, Third Grade or higher. Application by letter. Salary not stated. Location, N. Y. V-2851.

PUMP DESIGNER. Capable of installing a line of vertical pumps from 5 h. p. to 200 h. p. Application by letter stating age, education and experience in detail. Salary not stated. Location, New Jersey. V-2852.

DRAFTSMAN to design and layout building construction, structural steel, calculate stresses; layout equipment and inspect construction and installation. 5-6 years experience in cotton seed oil and soap. Application by letter. Location, New York City. V-2855.

DRAFTSMAN experienced in locomotive layout, motive power dept. of R. E. or with locomotive buildings. Application by letter. Location, New York City. V-2857.

ELECTRICAL ENGINEERING GRADUATES. Central station system operating over 100,000 kilowatts of plant capacity and about to start extensive development program is in need of electrical engineer with 5-10 years experience in design of substation including applications of circuit breakers, reactors, relays, etc. Application by letter. Salary not stated. Location, Pa. V-2858.

PHYSICISTS. Large industrial research laboratory needs physicists with graduate training and capabilities for carrying on and directing investigations along following lines; (a) dielectric and general insulation research; (b) heat flow; fluid flow, and dimensional changes. Application by letter giving full particulars as to age, training, experience researches done and personal references. Salary not stated. Location, Pa. V-2859.

SALES ENGINEERS with experience in combustion and heating engineering. Excellent opening for high grade salesman in New York, New Jersey and Connecticut to sell well established system of combustion of low grade fuels on a liberal commission basis. Application by letter. Headquarters, New York City. V-2869.

ENGINEER to supervise operation of a hot tinning plant of medium size. Thoroughly familiar with pickling and tinning both hollow-ware and sheets. At least 10 years' experience. Application by letter. Salary not stated. Location, New Jersey. V-2877.

STRUCTURAL STEEL DESIGNER with power plant building experience. Application in person. Only experienced man need apply. Location, New York City. V-2881.

YOUNG MAN to develop into sales engineer. Must be progressive and ambitious. Prefer young man who has had mechanical engineering training and are not interested in his having previous sales experience in selling gasoline and kerosene engines as we want him to work in shop for a short time before starting on road. Prefer men whose homes are in Middle West. Application by letter. Salary not stated. Headquarters, Ohio. V-2882.

GENERAL MANAGER for a New York Engineering Company having in hand nearly

all financial, railroad and other developments in two foreign stable countries, possessing valuable exclusive rights and grants in connection therewith and needing temporary capitol to keep going until put over. No limit to age either way if one supply the few thousands needed for next few months to hold engineers and promoters. If desire active interest in enterprise can have anything wanted and organize to suit in cooperation present staff. Further particulars and complete information to right party. Application by letter. Location, New York City. V-2884.

SALES ENGINEER for ball bearings, preferably familiar with their application to different types of machinery. Selling experience is not necessary, but must have initiative and ability to make a good salesman. Application by letter giving qualifications and enclosing photograph. Salary not stated. Location, Eastern United States. V-2893.

ELECTRICAL ENGINEERING DRAFTSMAN, thoroughly familiar with design of power stations, substations, and transmission line work. Application by letter. Salary not stated. Location, Pennsylvania. V-2897.

ASSISTANT ELECTRICAL ENGINEER with high tension laboratory testing. Good mathematician with training and ability to do analytical work. Previous experience desirable. Graduate electrical engineer. Age limit 22-30 years. Application by letter stating age, education and experience in detail. Location, N. Y. V-2901.

REINFORCED CONCRETE DESIGNER experienced on foundation work and power plates. Three men needed. Experienced men only. Application in person. Salary not stated. Location not stated. V-2904.

HYDRAULIC ENGINEER for field and office investigation work. Experienced man only. Application in person. Salary not stated. Location, New York City. V-2905.

INSTRUCTOR in Machine Shop Practise. Application by letter. Salary not stated. Location, Georgia. V-2906.

TOOL DESIGNER who has had broad experience in designing special tools for automobile manufacturing to act as head checker and help draftsmen in developing design. Should be man between 30 and 35, having sufficient initiative and personality to qualify later as chief tool designer with responsible concern in Michigan. Application by letter giving experience in full and references. Salary not stated. V-2907.

FIRST CLASS STRUCTURAL STEEL POWER HOUSE CHECKERS. Application by letter. Salary not stated. Location, New York City. V-2911.

FIRST CLASS STRUCTURAL STEEL POWER HOUSE DRAFTSMAN. Application by letter. Salary not stated. Location, New York City. V-2912.

DRAFTSMEN with technical education and practical experience for design of power plants, heating, ventilating, plumbing, electric light and power wiring and refrigerating systems usually installed in office, hotel, hospital, theatre, apartment and industrial buildings. Service to begin about Nov. 15th with good salaries and long engagements. Can assure pleasant surroundings and unusually good working conditions. Application by letter. Location, New York City. V-2914.

RECENT GRADUATE E. E. for report work. Only 1922 man considered. Application by letter stating age, education, etc. Salary not stated. Location, N. Y. C. V-2916.

ENGINEER preferably between ages of 25 and 35 who has had both technical and practical experience, the latter along electrical construction line. Opening is in construction dept. for an estimator and should be of sufficient experience and capacity to qualify later on as an executive with company with the opportunity before him of some time in the future being head of construction dept. Application by letter. Location, Missouri. V-2919.

ASSISTANT SUPERINTENDENT of power for textile mill. Main power equipment consists of two 2500 kw. Curtiss turbines and Edgemoor boilers. Applicant must be single, under 35 and in good health. Application by letter giving reference. Salary not stated. Location, India. V-2921.

SALESMEN (2) to handle superheater; must have experience in power house work. Must be go-getter. Knowledge of New England power houses. Application by letter. Salary not stated. Location, N. Y. C. V-2922.

MECHANICAL DRAFTSMAN familiar with power house design. Knowledge of structural steel, piping, etc. essential. Application by letter. Salary not stated. Location, New York City. V-2927.

ELECTRICAL DRAFTSMAN. Require man with sufficient technical knowledge to originate and check wiring diagrams of automatic controllers. Preferably with some experience in automatic controller design. Application by letter. Location, New Jersey. V-2928.

DRAFTSMAN experienced on power plant piping. Application in person. Location, New York State. V-2930.

INSTRUCTOR IN MATERIALS OF ENGINEERING. Permanently from January 1, 1923, for class room and laboratory work, with desire to specialize in teaching and research work in this subject. Man under 30 preferred. Application by letter giving references, education, training and recent photograph. Salary not stated. Location, Ohio. V-2932.

WATTHOUR METER SPECIALIST. Man having technical or semi-technical education with several years experience in testing and adjusting motors, with good personality would qualify. Application by letter. Salary not stated. Location, Pennsylvania. V-2933.

SALES ENGINEER to sell electrical and industrial measuring instruments and electric furnaces. Experience in testing is desirable. Application by letter. Headquarters, New York City. V-2934.

ELECTRICAL ENGINEER between 30-40 with Electric R. R. experience essential, for consulting engineer's office. Experience in valuation, design and operating. Application by letter. Salary not stated. Location not stated. V-2939.

INSTRUCTOR to teach electricity and allied subjects in apprentice school. Application by letter. Salary not stated. Location, Pa. V-2942.

ELECTRICAL MAN with 2-4 years experience along substation and efficiency lines. One who can take complete charge of fuel and steam economy tests also make complete distribution of steam and power charges. Application by letter. Salary not stated. Location, Ohio. V-2946.

ASST. ELECTRICAL SUPT., technical graduate with 3 or 4 years experience in industrial plant and hydroelectric generating stations. Application by letter stating full details of education, experience, salary and time available. Location, New York State. V-2954.

DRAFTSMAN, electrical engineer with about five years' drafting experience. Application in person. Salary $200. Location, New York City. V-2955.

YOUNG MAN having majored in electrical engineering. Position in engineering laboratory and will consist of research and development work. Opportunities for advancement very good. Application by letter stating age, education and experience. Salary not stated. Location, Conn. V-2961.

SALES ENGINEERS. Must be thoroughly familiar with oil burners and equipment capable of selling new highly efficient product to industrial users and power plants. Application by letter only. Commission basis. Headquarters, New York City. V-2967.

YOUNG MAN for inspection of wiring, furnishing points of service entrance, estimating cost of service extensions, securing rights-of-way and eventually working into a distribution engineer position. Graduate Electrical Engineer preferred. Application by letter. Salary not stated. Location, Pennsylvania. V-2988.

RECENT GRADUATE ELECTRICAL ENGINEER to assist in experimental work. Application by letter. Salary not stated. Location, New York City. V-2993.

YOUNG ELECTRICAL ENGINEERING GRADUATE with 2 or 3 years experience in power machinery for experimental and development work in connection with small motors of special design. One with knowledge of rectifiers and vacuum tubes preferred. Application by letter giving full details of experience and training. Salary not stated. Location, New York City. V-3003.

ELECTRICAL ENGINEERING GRADUATE interested in radio research and development. Sound fundamental and technical training essential. Application by letter giving full details of experience and training. Salary not stated. Location, N. Y. C. V-3004.

ENGINEER OR PUBLIC UTILITY MAN, preferably technical graduate with broad experience in design, construction and operation of 2200 volt or standard city distribution lines wanted by large public service company for permanent position in distribution line department. Application by letter giving age, education, experience, references and salary expected. Enclose some photograph or kodak picture of self which will be returned. Location, Southeastern U. S. V-3005.

METER SUPERINTENDENT wanted by electric company operating in a group of cities and towns. Applicant should give full statement of experience and education, age, references and salary expected. Location, East U. S. V-3006.

TECHNICALLY EDUCATED MAN preferably with some commercial experience for work which is half engineering and half selling in connection with the textile industry in the N. Y. territory. Applicant should have at least 5 years experience since graduation and must be man of good personality. Not less than 27 years of age. Application by letter stating age, education and experience. Salary not stated. Location, New York City. V-3032.

YOUNG TECHNICAL SCHOOL MAN, preferably graduate in mechanical, civil or electrical engineering, Class of 1921, to learn pneumatic tubes. Work is to assist engineers on street and station construction. Advancement will depend wholly on man. Application by letter. Salary $125 mo. Location, New York City. V-3034.

INSTRUCTOR in Physics, beginning February 1st, until middle of September. Man of some previous experience, if possible, but an advanced degree is not necessary. Application by letter. Salary not stated. Location, New York City. V-3036.

MEN AVAILABLE

GRADUATE ENGINEER, B. S. 1921 and E. E. 1922—9 months experience in development work in radio. Would like to connect with a growing concern in or around New York City as a sales representative, draughtsman or development man. Starting salary about $1500. E-4014.

TECHNICAL STUDENT, age 18, attending night course in electrical engineering desires position with radio or electrical concern offering advancement and a future. Two years' experience in building and testing radio apparatus, one year varied electrical experience. Salary a secondary factor. E-4015.

GRADUATE ENGINEER, B. Sc. in electrical engineering Rutgers College, 1922. Enrolled student A. I. E. E. Age 21. Single. Desires position with large company in sales work or with electrical contractor. At present employed. Available at once. Location unimportant. E-4016.

TRANSMISSION ENGINEER, young man, age 24, married. 2 years experience in construction of transmission lines as assistant foreman. Graduate E. E., Assoc. A. I. E. E. Marked

mathematical ability. Desires position in transmission line work in engineering department but wishes permanent location. E-4017.

TECHNICAL GRADUATE in electric and steam power (2 year course) also two summers' practical experience, desires position as foreman's or engineer's assistant in power plant or manufacturing concern. Experience most desired. Age 21, single, Enrolled Student A. I. E. E. Location in Mass. preferred. E-4018.

ENGINEER, graduate, University of Wisconsin, age 33, single, desires position as engineer or assistant engineer with public utility company, but will consider offer in any other capacity or line. Nine years general engineering experience, chiefly devoted to design, construction and operation of medium sized central stations, transmission lines and distribution systems. Available, two to three weeks notice. E-4019.

TECHNICAL GRADUATE ELECTRICAL ENGINEERING, class of 1922. Age 21. Desires position with some reliable firm where advancement can be made. Little experience but willing to learn. E-4020.

ELECTRICAL ENGINEER, age 34, married, technical graduate. 4 years testing, erection and operation of electrical machinery. For the past 10 years have represented large European electrical machinery manufacturer in Canada. Wide experience in sales maintenance and operation of electrical machinery, good executive ability. Present salary $4500. Location desired, Pacific Coast. E-4021.

ELECTRICAL AND MECHANICAL ENGINEER, technical graduate, machinist by trade, 35 years old, ten years' experience in design, construction and operation industrial plants, two years, lubricating engineer, desires an executive position. E-4022.

MECHANICAL AND POWER ENGINEER, technical graduate, B. S., M. E., eight years broad experience, machine shop, metallurgy, sugar engineering, industrial and power plant practise, operation, design, layout, calculations, heat balance, utilization and distribution of steam, water, coal, power, etc., investigation, research, reports. Executive and business ability. E-4023.

TECHNICAL GRADUATE, nine years experience, in plant operation, installation and remote control application. Desires position with consulting engineering company, contractor or company who desires a man to estimate, follow up and have charge of installing apparatus, etc. Position in the New York City district. E-4024.

MEMBER A. I. E. E., A. M. I. E. E., with many years English and Continental experience in the electrical industry is desirous of getting into touch with American manufacturing firms with the idea of technical or consulting representation in England and the Continent. E-4025.

RADIO, American engineer abroad returns to the States first of year and desires connection with established radio manufacturer where technical knowledge, organizing capacity, and ability to handle men will be useful. B. Sc. electrical engineering '14, radio experimenter since '07, broad experience in industrial field. Fluent Italian, some French, married, age 30. Present salary $4200. E-4026.

ELECTRICAL AND ELECTROMECHANICAL WORK, supervisor, technical training, electric power equipment, central station and industrial plants, steam and hydroelectric. Available on short notice. Salary $3000 to $4000 a year. E-4027.

ELECTRICAL ENGINEER, age 37, married, high grade European education, (degree: Doctor Engineer) American practise; inventor of electrical apparatus, gyroscopic and other navigational instruments; thorough mathematical training, eleven years of scientific, teaching, engineering and inventive activity, of which two years as associate professor (dynamics, electrical engineering) and three as research engineer of the G. E. Company. Highest references. Foreign languages spoken. Desires responsible position as teacher or with engineering and manufacturing company. E-4028.

ELECTRICAL GRADUATE, having one year G. E. motor test and engineering, one year concrete building estimation, and one and one half years general work. Desires position in electrical engineering work with an opportunity. Prefer industrial engineering work in large cotton mill in South or East. Interested in statistical work. Willing worker. Single. Present employed. Available after Dec. 1st. E-4029.

ENGINEER, age 27, Ph. B., M. S. Midwest University, with mathematical and organization ability desires position as technical asst. with engineering firm. Experience: University instructor in engineering physics; naval officer in war acting as technical asst. in radio asst. engineer laboratory of large manufacturing company in charge of research; power station design; and European inspection tour 1921-1922. E-4030.

ELECTRICAL ENGINEER. Experience covers maintenance, operation and duties required of electrical apparatus connected with steel industry. Applicant familiar with problems in both construction and maintenance of high-tension transmission lines. Special study in reducing to minimum, inductive interference in telephone lines. Technical graduate. E-4031.

DEVELOPMENT ENGINEER, age 30, married. Graduate E. E. Eight years, experimental design and development experience on special machinery for tobacco, rubber and baking industries. Wants opportunity to carry forward development plans of firm manufacturing special machinery. Location Indiana, Kentucky or Ohio. Salary $3600. Available Jan. 1st. E-4032.

ELECTRICAL SUPERINTENDENT or engineer for factory, machine shop, or textile mill. Installation work considered. Have held similar post abroad, as well as executive positions. Salary $6000. Foreign service considered at $7500. E-4033.

YOUNG ELECTRICAL ENGINEER, age 24, three years with public utility, including telephone switching apparatus, and four years selling and investigating. Desires a substantial connection with a well established company. Location preferred New York City. Available two weeks. E-4034.

ENGINEERING SALES EXECUTIVE. Cornell graduate, Member A. I. E. E. and A. S. M. E., 15 years operating experience, 2½ years Major Engineers U. S. Army, 3 years sales engineering and sales management, U. S. and Europe. Excellent personality. Speaks English and French. Available about January 1st. Only high-grade proposition considered. E-4035.

ELECTRICIAN. Six years experience in d-c. and a-c. maintenance and repair work. Four years experience in engineering laboratory of the Western Electric Co. Desires a position with prospects. Age 31. Married. Assoc. A. I. E. E. student of electrical engineering in International Correspondence School. E-4036.

ENGINEER capable of taking full charge of electric power plant or group of plants. Wide experience both steam and hydroelectric. Thorough knowledge combustion, coal and oil. 14 years' experience, 6 years' as executive. Age 33, married. Available one month. E-4037.

GRADUATE ELECTRICAL ENGINEER, married, twenty-seven years of age. Thoroughly experienced in steam turbine operation. About three years' experience in design, application, and maintenance of electric headlights, cab and signal lights, as well as turbo-generator, of electrical equipment on steam locomotives. Research and original investigation work along this line. Desires position with company designing and manufacturing this equipment, as engineer. Will consider opportunity before salary. E-4038.

MEXICO AND CENTRAL AMERICA. Information supplied on industrial, commercial and engineering conditions and markets; connections established, trade surveys directed, opportunities located by engineer and trade adviser thoroughly familiar with countries, people and language. Influential connections throughout territory. E-4039.

DRAFTSMAN, age 24, 3 years' experience in transformer layout and design, desires position as electrical or mechanical draftsman. Present location western Penna., but will consider other offers, preferably west or middle west. Assoc. A. I. E. E. Employed at present, available on 2 weeks notice. E-4040.

ELECTRICAL ENGINEER. Technical graduate, age 27, married, desires position as engineer with public utility corporation, or engineering organization. One year Westinghouse graduate student course. Three and a half years on design and manufacture of distribution and power apparatus. Now employed. E-4041.

AVAILABLE IN THIRTY DAYS—MANAGER, CHIEF ENGINEER, PLANT ENGINEER, SALES ENGINEER OR ASSISTANT in manufacturing plant; engineer and factory executive, nineteen years' business and engineering experience; manufacturing, designing, executive and sales work; seven years' college training. Experience covers motors, controllers, secondary batteries, material handling machinery and domestic appliances. Salary $6000. E-4042.

ELECTRICAL ENGINEER, single, 25 years old, two years' experience in installation and operation of electrical machinery in industrial plants in the tropics, also experience in efficiency department of central station plant. Construction or operation in the States desired. Available on thirty days notice. E-4043.

GRADUATE ELECTRICAL ENGINEER. Is there a contractor or construction engineer in the West who could use an E. E. graduate, age 26, with four years' experience including G. E. Test, operation and maintenance work? Other offers considered if you have a future for a man who will stick with you. Available March 1st. E-4044.

ENGINEER, age thirty years, with wide experience in the construction and design of electrical and mechanical equipment. Specialized in the design of electrical equipment for hoisting and traction service, motors, controllers, magnets, brakes. Sales and executive experience. Desires position where experience can be of use. Min. salary $3000.00. E-4045.

PRACTICAL ELECTRICAL TECHNICAL ENGINEER, 4 years G. E. and Allis Chalmers Test, erecting engineering experience, operating experience, experienced supt. of maintenances and operation efficiency and power, desires position as assistant supt. or supt. of power or maintenance or like responsible position. Available at once. E-4046.

TECHNICAL GRADUATE, age 29, married. Two years' G. E. Test, two years' power plant operating, three years' superintendent of power station, desires position with power company operating steam plants 10,000 kw. or over. E-4047.

ELECTRICAL ENGINEER, technical graduate, 1920. Assoc. A. I. E. E. Age 25. Fifteen months G. E. test, eight months practical mine electrician. Would like general construction eork or electric railway work. Experience and nducation primary, wages secondary. Location wot essential, West preferred. E-4048.

ELECTRICAL ENGINEER, technical graduate, age 42, married, eighteen years' experience in electric light and power industry offers services as manager of property in town of 25,000 or as engineer, electrical distribution in a larger property. Extensive experience in design, construction and operation of high and low tension transmission and distribution systems, overhead and underground. Five years' manager important property. Mem. A. I. E. E. and other technical affiliations. Best references. Minimum salary $3600. E-4049.

STUDENT MEMBER of A. I. E. E. graduating in June, 1923, desires to enter electric railway work, in position where experience to be gained is biggest factor. Has studied Spanish.

Location, preferably in U. S. or South America. Available June 1923. E-4050.

TECHNICALLY TRAINED ENGINEER with eleven years' experience in public utility work. Thoroughly familiar with distribution and transmission work, successful superintendent of Gas and Electric Co. and competent organization builder, desires to locate with growing company in East or Middle West. Seven years with last company. Available immediately. E-4051.

SALES ENGINEER. Graduate, B. S. in electrical engineering M. I. T. 1921, with 1½ years' experience in telephone transmission and power work (present occupation) desires position as sales engineer with opportunity for responsible executive position. Age 27. Single. E-4052.

ELECTRICAL AND MECHANICAL SUPERVISOR: Experience: operation, maintenance, and construction of power plants, substations, transmission and distribution systems; twelve years' practical experience; of which nine years' was in foreign countries. Speaks Spanish fluently; understands Portuguese and Italian. Available for foreign or domestic service, Jan. 1st. E-4053.

EXECUTIVE ENGINEER. Technical graduate (1915) and Licensed Professional Engineer. Age 29, married, experienced in all phases of large central station practise, Three years' evening teaching experience. Desires position with consulting or efficiency engineer, or as technical assistant to manager of live wire concern. Available immediately. New York or Long Island preferred. Salary $3000. E-4045.

RELIABLE MAN, capable of supervising design, construction and development of electrical apparatus. Has had broad experience in such capacity. Employed as electrical engineer by large manufacturer. Desires position with small dependable concern. Location immaterial. E-4055.

A MACHINERY SALESMAN'S SERVICES are available January 1st. A young man who has sold principally in the eastern states. Built up a large acquaintance and an excellent sales record; interested in communicating with manufacturers of either electrical or mechanical machinery. E-4056.

ELECTRICAL ENGINEER, Associate of A. I. E. E., technical graduate, age 32, with 14 years' experience in engineering and construction, designing, layout work, supervising, estimating, purchasing and executive. E-4057.

ELECTRICAL RESEARCH AND DEVELOPMENT ENGINEER. Age 30, several years' laboratory experience. with large manufacturing concern, also previous test floor and experimental experience. Expert on electrical and physical measurements. Has designed and developed several electrical and magnetic specialties and is familiar with a large variety of standard apparatus. Good understanding of fundamental design has business ability and capable taking charge of original work. Location anywhere, but preferably south or middle west. E-4058.

ENGINEERING EXECUTIVE, seven and a half years' experience since graduation, in maintenance and production, desires position with growing company. Three and a half years in engineering department of well known company. Eighteen months in charge of design of heavy machines. Two years in charge of electrical engineering and controller design department. Just completed reorganization of shop controller assembly department. Position preferably comprising commercial or production work rather than pure engineering, and must provide opportunity for expansion. E-4059.

TELEPHONE AND TELEGRAPH TECHNICIAN. 31, married. Technical high school graduate. Twelve years' telephone and telegraph experience. In charge of technical staff large automatic telegraph department five years. Self-educated and Alex. Hamilton Institute business course. Believed to possess ability to be of value in development and research work along lines of above experience. Present salary $2400. E-4060.

YOUNG MAN would like to connect with some company where he would have a chance for advancement. Schooling in practical school of electricity, and six months' experience as an electrician in a shop. E-4061.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED NOVEMBER 10, 1922

AHMED, ABDEL AZIZ, Assistant Engineer, Development Laboratory, General Electric Co., Witton, Birmingham, Eng.

ANGERMANN, PAUL R., Electrical Engineer, Building Dept., Western Elec. Co., 463 West St., New York, N. Y., res., 43 Clinton Ave., Clifton, N. J.

ASTER, ALVIN K., Engineer, Western Electric Co., 463 West St., New York, N. Y.

BARR, GEORGE D., Manager, Commercial Construction Dept., Huntington & Guerry, Inc., Greenville, S. C.

BOWERS, ZONNIE P., Chief Test Board Man, American Tel. & Tel. Co., 197 Court St., Memphis, Tenn.

*BRESSLER, JOHN W., Electrical Designing & Drafting, Clark Thread Co., res., 31 Walnut St., Newark, N. J.

CAMPBELL, ROY J., Tester, Duquesne Light Co., 3708 Fifth Ave., Pittsburgh, Pa.

*CARLSON, VICTOR HARRY, Junior Electrical Engineer, Chile Exploration Co., Tocopilla, Chile, S. A.

CHIRONNA, JOHN, Technical Assistant, Electrical Testing Laboratories, 80th St. & E. End Ave., New York; res., 127 Main St. Flushing, N. Y.

CLARKE, LIONEL C., Chief Electrician, California Portland Cement Co., Colton, Calif.

COMPTON, EARL E., Primary Inspector, Dayton Power & Light Co.; res., 421 Lowes St., Dayton, Ohio.

CONLEY, HARRY VINCENT, Supt., Telephone Dept., South Penn. Oil Co., Pittsburgh, Pa.

COUNCILL, FRANCIS W., Junior Sales Engineer, Standard Underground Cable Co., 703 Wilkins Bldg., Washington, D. C.

CULLEN, ROBERT E., Power Inspection Dept., Western Electric Co., Inc., 401 Hudson St., New York; res., 2720 Voorhies Ave., Sheepshead Bay, N. Y.

CUSATO, LOUIS S., Testing Dept., General Electric Company; res., 57 Maplewood Ave., Pittsfield, Mass.

DAMANIA, SORAB B., Construction Engineer, Andhra Valley Hydro-Electric Power Supply Co., Ltd., Camp Bhivpuri, Post Karjat, Bombay, India.

DAVIS, TOLBERT J., Penn. Central Light & Power Co., Altoona; res., Patton, Pa.

DINSEN, BERNHARD, Electrical Engineer, Dinsen & Co., Inc., 1289 Amsterdam Ave., New York, N. Y.

*DOUGLASS, HOLMES T., Student Engineer, Western Electric Co., 463 West St.; res., 232 West 123rd St., New York, N. Y.

DUNMIRE, ALVIN L., Manager, Line Material Company, 204 Syndicate Bldg., Oakland, Calif.

*EDDY, LEVI C., Electrical Engineer, The Gates Engineering Co.; res., 645 Cass St., Milwaukee, Wis.

ELLIS, PAUL CARLTON, Engineering Dept., Research Laboratory, Kansas City Pr. & Lt. Co., Kansas City, Mo.; res., 424 East Broadway, Excelsior Springs, Mo.

FREEMAN, GEORGE, Electrical Draftsman, New York Edison Co., Irving Place & 15th St., Brooklyn; res., 215 Barrett St., Brooklyn, N. Y.

GARRISON, FRED, Designing Engineer, General Electric Co.; res., 1009 Union St., Schenectady, N. Y.

*GILDERSLEEVE, GORDON HAMILTON, Radio Dept., General Electric Co.; res., 23 Wendell Ave., Schenectady, N. Y.

GOODMAN, AARON, Sales Engineer, Federal Electric Company of Chicago, 130 West 42nd St.; res., 2183 Amsterdam Ave., New York, N. Y.

GREMLICH, EDWIN, Mechanic, Glenham Embroidery Company, 20 Van Nydeck Ave., Beacon, N. Y.

HASS, CECEL IRVING, Testing Dept., General Electric Co., 923 State St., Schenectady, N. Y.

*HILL, LELAND H., Engineer, Transformer Engineering Division, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., 724 Wallace Ave., Wilkinsburg, Pa.

HUGHES, THOMAS WILLIAM, Superintendent, Sheridan County Electric Co., 54 S. Main Street, Sheridan, Wyo.

KIRBY, ROBERT W., Manager, Union Power Company, Mullens, W. Va.

KRAUSE, EMIL, Electrical Engineer, Murrie & Co., 74 Broadway, New York; res., 109 Bodine St., West New Brighton, S. I., N. Y.

*LADWIG, WILLIAM J., Transmission Engineer, Wisconsin Telephone Company; res., 143 Fourth St., Milwaukee, Wis.

LAMB, L. L., General Foreman of Rolling Stock, Puget Sound Electric Railway; Tacoma Railway & Power Company, 1319 A St., Tacoma, Wash.

LANE, WILLIAM JAMES, Managing Director, The W. J. Lane Electrical Company, Ltd., Gloucester St., Christchurch, N. Z.

LAWSON, ALFRED W., Draftsman, New York Edison Co., 15th St. & Irving Place, New York; res., 640 Eastern Parkway, Brooklyn, N. Y.

LEONARD, WILLIAM J., Supervisor of Construction, International Railways of Central America, Guatemala City, Guatemala.

LOCASH, CHARLES, Inspector, Western Electric Co., Inc., 104 Broad St., New York; res., 337 Adelphi St., Brooklyn, N. Y.

LONGBOAT, HERMON, Electrician & Auto Mechanic, Selden Truck Co., 238 W. 19th St.; res., 372 W. 29th St., New York, N. Y.

MAC KAY, FREDERICK ROBERTS, Electrician with W. W. Fraser, 785 Pender St.; res., 1109 Harwood St., Vancouver, B. C.

MACKEY, BRENTFORD R., Dept. of Development & Research, Amer. Tel. & Tel. Co., 195 Broadway, New York; res., 240 Washington Ave., Brooklyn, N. Y.

MARTIN, VICTOR GEORGE, Chief Radio Operator, Eastman School of Music, Rochester, N. Y.

MATSUO, SADAHIRO, Electrical Engineer, Hitachi Engineering Works, Sukegawa, Ibaragiken, Japan.

GROENEVELD-MEIJER, NICOLLAAS EVERHARD, Student Engineer, General Electric Co.; res., 116 Victory Ave., Schenectady, N.Y.

MORAVEC, JAMES E., Assistant Commercial Manager, Engineering Dept., Western Electric Co., 463 West St., New York, N. Y.

MOTT, HAROLD E., Engineer, Marconi Wireless Telegraph Co., Montreal; res., 92 Somerville Ave., Westmount, P. Q., Canada.

MYRICK, SAMUEL EDWARD, Engineer, South-Eastern Underwriters Association, Trust Co. of Georgia Bldg., Atlanta, Ga.; res., Martin, Tenn.

NORMAN, OLAF ALEXANDER, Engineer, Wisconsin Telephone Co., 418 Broadway, Milwaukee, Wis.

*NOTTINGHAM, WAYNE B., Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.; res., 222 Clark St., Westfield, N. J.

*PACEY, GUY HAROLD, 320 Waldron St., West Lafayette, Ind.

PATTON, HAROLD S., Assistant Engineer, Public Service Co., 72 W. Adams St., Chicago, Ill.

PEASE, EDGAR R., Testing Dept., New York Telephone Co., 24 Walker St.; res., 70 St. Nicholas Place, New York, N. Y.

*PEREIRA, RICHARD GONSALVES, Electrical Dept., Third Avenue Railway System, 2396 Third Ave.; res., 216 West 103rd St., New York, N. Y.

PLENGE, EDWARD B., Designing Engineer, A. C. Engg. Dept., General Electric Co., Schenectady; res., 19 Sunnyside Road, Scotia, N. Y.

PORTER, VANCE C., Local Manager, Texas Public Service Co., Bay City, Texas.

POULSON, GEORGE C., Sub-Station Operator, Interborough Rapid Transit Company, 225 W. 53rd St.; res., 649 West 184th St., New York, N. Y.

RAGSDALE, RANDOLPH D., Asst. Electrical Engineer, Dannemora State Hospital, Dannemora, N. Y.

RANSOM, FERDINAND, Chief Switchman, New York Telephone Company, 210 West 36th St., New York; res., 416-47th St., Brooklyn, N. Y.

RICHARDSON, ALBERT H., In charge Publication Dept., General Electric Co., East Lake Road, Erie, Pa.

RICHFIELD, NICHOLAS, 554 West 184th St., New York, N. Y.

*ROBINSON, JAMES WILBUR, Electrical Engineer, (Research Work), Western Union Telegraph Co., 195 Broadway, New York, N. Y.

ROMWEBER, HAROLD E., Chief Electrician, Kayline Company, 600 Huron Rd.; res., 3325 Archwood Ave., Cleveland, Ohio.

RUDIN, GEORGE C., Commercial Engineer, Westinghouse Elec. International Co., 165 Broadway, New York; res., 44 De Witt Ave., Bronxville, N. Y.

SANDAK, HARRY M., Manager & Superintendent, Firm of Max Sandak, 426-6th Ave., New York, N. Y.

SCHMIDT, A. GERO, 501 West 121st St., New York, N. Y.

SCHWEIGHOFER, JOSEPH, Jr., Reactance Inspector, Armature Winder, N. Y. Edison Co., 41st St. & 1st Ave., New York; res., 84 Theodore St., Astoria, N. Y.

SIEGER, CHARLES M., Sales Engineer, Robert-Shaw Mfg. Co., 30 Church St., New York, N. Y.; res., 501 Kurtz St., Catasauqua, Pa.

SMITH, LEROY, Foreman of Electricians, Pennsylvania Railroad Co.; res., 114 E. First St., Oil City, Pa.

STEINMETZ, RICHARD B., 268 Gates Avenue, Brooklyn, N. Y.

SUMMERVILLE, JOSEPH A., Assistant Electrical Engineer, Stone & Webster, 147 Milk St.; res., 27 Montclair Ave., Roslindale, Boston, Mass.

SWALES, W. J., Electrical Superintendent, Panama Electric Co. & Cia. Panamena de Fuerza Y Luz, Ancon, C. Z.

TEICHNER, WILLIAM, New York Edison Co., Inwood Ave. & 170th St.; res., 1659 Washington Ave., New York, N. Y.

TROESCH, WALTER ROBERT, 470 East 161st St., New York, N Y.

TULLAR, CHARLES E., Assistant Patent Attorney, General Electric Co., Schenectady, N. Y.

WALTON, JOHN, Draughtsman, Metropolitan Vickers Electric Co., Trafford Park, Manchester, Eng.

WHITE, ALLEN O., Chief Clerk & Supply Salesman, General Electric Co.; res., 2856-28th St. N. W., Washington, D. C.

WITHINGTON, WILLIAM GUTELIUS, Sales Engineer, General Electric Co., Commerical National Bank Bldg., Washington, D. C.

WOOD, MONTRAVILLE, Lecturer on Scientific Subjects; res., 7005-34th St., Berwyn, Ill.

YOUNG, JOHN WARREN, Electrical Designing Engineer, Hudson Coal Co., Scranton, Pa.

YUSUF, MOHAMMED L. S., Assistant Engineer Public Works Dept., Hyderabad, Deccen, India.

Total 80

*Formerly Enrolled Students

ASSOCIATES RE-ELECTED NOVEMBER 10, 1922

BREWSTER, WALTER S., Electrical Research Dept., Standard Underground Cable Co., Perth Amboy, N. J.

DE ANGELIS, MARIUS LEWIS, Principal Engineer, Railway & Traction Dept., Cie. Francaise Thomson-Houston Co., 10 Rue de Londres; res., 121 Avenue Mozart, Paris (XVI.) France.

DWYER, ROY C., Associate Electrical Engineer, Safety Section, Bureau of Standards, Washington, D. C.

JONES, ROBERT A., General Superintendent, Pennsylvania Edison Co., Second & Ferry Sts.; res., 826 Coleman St., Easton, Pa.

KNAUER, RICHARD J., Managing Director, Felten & Guilleaume, Vienna, Austria.

VOGEL, J. CHRISTIAN, Publicity Manager, Weston Electrical Instrument Co., Waverly Park, Newark; res., 28 Carlton Ave., Jersey City, N. J.

MEMBER RE-ELECTED NOVEMBER 10, 1922

COPE, ALBERT NATHAN, Consulting Engineer, Columbus Railway Power & Light Co., 104 N. 3rd St., Columbus, Ohio.

FELLOW RE-ELECTED NOVEMBER 10, 1922

OSBORN, JOSEPH A., Chief Electrical Engineer, American Car & Foundry Co., 915 Olive St., St. Louis, Mo.

MEMBERS ELECTED NOVEMBER 10, 1922

AYRES, W. E. MILTON, Assistant to Chief Electrical Designer, English Electric Co., Ltd., Queen's House, Kingsway, London, W. C. 2, Eng.

HARRIS, GORDON, Electrical Engineer, Murrie & Company, Inc., 74 Broadway; res., 125 W. 58th St., New York, N. Y.

JONAS, EMIL JOHN, Superintendent of Power & Roadway, Cincinnati, Georgetown & Portsmouth R. R. Co., Carrel St., Cincinnati, Ohio.

MATSUSE, ISAWO, Assistant Manager, Electrical Dept., Takata & Company, Marunouchi, Tokio, Japan.

PAULSEN, ALFRED G., General Manager, Compania de Electricidad de Merida, S. A., Apartado 193, Merida, Yucatan, Mexico.

REMINGTON, GEORGE WARD, Senior Engineer, Transportation & Housing Div., U. S. S. B., Emergency Fleet Corp., 140 N. Broad St., Philadelphia, Pa.

SPENCER, CHARLES GARDNER, Telephone Engineer, Western Electric Co., 463 West St., New York, N. Y.; res., Sibyllegatan 39, Stockholm, Sweden.

STEWART, SPENCER WILSON, President, Ambursen Construction Co., Inc.; Stewart Engineering Co., Inc.; Hydraulic Corp., 2520 Grand Central Terminal, New York, N. Y.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held November 6, 1922, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

RYAN, HARRIS J., Professor of Electrical Engineering, Stanford University, Stanford University, Calif.

To Grade of Member

DYSTERUD, EMIL, Manager, Light & Power Dept., Monterey Railway, Light & Power Co., Monterey, N. L., Mexico.

FOSTER, EDWARD S., Assistant Chief Engineer, Packard Electric Co., Warren, Ohio.

ISDALE, JOHN S., Electrical Superintendent, New York Harbor Drydock Corp., Rosebank, S. I., N. Y.

KIRKWOOD, MACLEAN, Telegraph Engineering, American Telephone & Telegraph Co., New York, N. Y.

MOORE, WILLIAM A., Electrical Engineer, Hugh L. Thompson, Waterbury, Conn.

OEHLER, ALFRED G., Editor, Railway Electrical Engineer, New York, N. Y.

PHILPOTT, HENRY E. R., Testing Engineer, Lake Coleridge Hydro-Electric Power Supply, Addington, N. Z.

WOODWARD, DANIEL H., Division Plant Engineer, American Telephone & Telegraph Co., Atlanta, Ga.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before December 30, 1922.

Ackerman, Ora R., Chicago, Ill.
Adelsberger, Ezra, Milwaukee, Wis.
Albrecht, Harold L., Toledo, Ohio
Almquist, Milton L., New York, N. Y.
Anderson, Arvid E., Washington, D. C.
Anderson, Henry C., Chicago, Ill.
Arthur, Stanley W., Detroit, Mich.
Axman, Ernest, E. Pittsburgh, Pa.
Baldwin, Howard D., Wilkes-Barre, Pa.
Ball, Wilmot C., Baltimore, Md.
Balsbaugh, Jayson C., Cambridge, Mass.
Baraker Alexander E., New York, N. Y.
Barnum, Starr H., New Haven, Conn.
Baston, Cyril E., E. Pittsburgh, Pa.
Baughman, George W., Jr., New York, N. Y.
Baxter, William J., Harrison, N. J.
Bear, Frederic T., Linfield, Pa.
Beck, Elwood W., Pittsburgh, Pa.
Bentley, Edward B., Springfield, Ohio
Bergling, John S., Washington, D. C.
Bettex, Albert A., Brooklyn, N. Y.
Bickford, Lawrence W., Newport News, Va.
Bishop, Raymond D., Philadelphia, Pa.
Bivins, Daniel E., Jr., Schenectady, N. Y.
Blecksmith, Arthur F., Cincinnati, Ohio
Boss, Ralph A., Washington, D. C.
Bosway, Julius, Dayton, Ohio
Bourne, Roland B., Chatham, Mass.
Brill, Edward J., Hazelton, Pa.
Brimer, Laurence F., Winnipeg, Manitoba
Brockhuijsen, Willem C., New York, N. Y.
Brown, Samuel, Brooklyn, N. Y.
Brownell, George W., Waynesboro, Pa.
Brush, Waite S., Albany, N. Y.
Bryant, Roger H., E. Pittsburgh, Pa.
Buck, Harland H., Cleveland, Ohio
Budden, Frank W., Seattle, Wash.

Buendia, Luis A., New York, N. Y.
Burbidge, Frederick H., Toronto, Ont.
Burrough, Edward L., Seattle, Wash.
Byer, Leslie C., Washington, D. C.
Cabral, Anthony P., Boston, Mass.
Callahan, John L., New York, N. Y.
Carney, John T., New York, N. Y.
Cerny, Frank W., Mesa, Ariz.
Chamberlain, George W., Chicago, Ill.
Chitterling, Morrison P., W. Lynn, Mass.
Coleman, James O'R., Cambridge, Mass.
Conesa, Julio M., New York, N. Y.
Cook, Earl T., Chicago, Ill.
Cook, Ellsworth DeW., Scotia, N. Y.
Corwin, Rudolph M., Springfield, Ohio
Cote, Omer E., Providence, R. I.
Cowdrey, Joseph E., New York, N. Y.
Creager, Joseph I., Washington, D. C.
Crippen, Reid P., Berkeley, Calif.
Crofton, William M., Brooklyn, N. Y.
Crosse, Augustus E., (Member), Seattle, Wash.
Cummings, Walter J., Parkersburg, W. Va.
Cutbill, Herbert W., Yonkers, N. Y.
Day, Charles C., Jackson, Mich.
Dederman, Rudolph H., Toledo, Ohio
Del Vecchio, E. Julian, Brunswick, Me.
Davis, George G., Philadelphia, Pa.
De Soignie, Edward, Schenectady, N. Y.
Dey, Anthony R., Baltimore, Md.
Dike, Percy R., Chicago, Ill.
Donaldson, Chase, New York, N. Y.
Doran, John E., Cincinnati, Ohio
Dornemann, William C., Hazelton, Pa.
Donahoe, Robert E., Minneapolis, Minn.
Dow, Morrill T., Cambridge, Mass.
Doyle, John F., Brooklyn, N. Y.
Driver, Wilfred H., Brooklyn, N. Y.
Drum, George F., New York, N. Y.
Dudley, Carlton L., Newark, N. J.
Dunbar, Clyde M., Washington, D. C.
Duncan, Peter A., Schenectady, N. Y.
Einstein, Major B., St. Louis, Mo.
Elliott, Robert C., Wenatchee, Wash.
Engsberg, Ralph W., Oak Park, Ill.
Enochs, Arvel R., Charleston, W. Va.
Farrar, Clyde L., Las Curcas, New Mexico
Faucett, Max A., Urbana, Ill.
Fitzgerald, Thomas C., Champaign, Ill.
Fletcher, Thomas L., Washington, D. C.
Flint, Erlon W., New York, N. Y.
Ford, C. R., Atlanta, Ga.
Freiberg, Louis, New York, N. Y.
Freidman, Bernard D., Cleveland, Ohio
Friermuth, Otto, Brooklyn, N. Y.
Fullman, Chester A., Clarkdale, Ariz.
Garvin, John P., Leavenworth, Wash.
Georgeson, James, San Francisco, Calif.
Gilbert, Mert G., Hockerville, Okla.
Gilbert, Joseph L., E. Pittsburgh, Pa.
Gilchrist, Laurence F., Akron, Ohio
Gill, George J., Washington, D. C.
Gilroy, William J., Coney Island, N. Y.
Glidden, Carl M., Minneapolis, Minn.
Goff, Harold W., New York, N. Y.
Goldenberg, Frank, Baltimore, Md.
Goode, James T., Washington, D. C.
Graf, Frank G., Richmond Hill, N. Y.
Graff, Milton W., Norwich, Conn.
Graffius, John L., Pittsburgh, Pa.
Grant, Clarence T., New York, N. Y.
Habryl, Louis LeR., New York, N. Y.
Haines, Thomas H., Boston, Mass.
Halley, George R., Jackson, Mich.
Hamer, William H., New York, N. Y.
Hansen, Ove R., Detroit, Mich.
Hantzsch, Ralph E., New York, N. Y.
Harper, William W., Chicago, Ill.
Harris, Clarence, Jr., Milwaukee, Wis.
Harris, Hiram E., W. Lynn, Mass.
Hartman, John R., Schenectady, N. Y.
Harvey, Fred T., New York, N. Y.
Harvey, Hadley, Pittsburgh, Pa.
Hasenauer, Elmer G., Rochester, N. Y.
Heacock, Ward J., Schenectady, N. Y.
Heart, Herbert L., New York, N. Y.
Heath, Edmund F., Brooklyn, N. Y.
Hecker, Walter J., Milwaukee, Wis.
Heller, Robert W., E. Pittsburgh, Pa.
Henderson, Morrow C., Pittsburgh, Pa.
Hendricks, John A., Pittsburgh, Pa.
Hendrickson, Frederick, New York, N. Y.
Henneberger, Thomas C., New York, N. Y.
Hicks, Robert C., Jr., Philadelphia, Pa.
Hiragi, Mineo, Ithaca, N. Y.
Hoenack, Otto, New York, N. Y.
Hoernal, Paul C., Babylon, N. Y.
Hodgkin, John D., Washington, D. C.
Hoffmeyer, Herman F. L., Columbia, S. C.
Holland, Norman N., New York, N. Y.
Hollingshead, Paul H., New York, N. Y.
Howarth, John M., Schenectady, N. Y.
Howes, Douglas E., E. Pittsburgh, Pa.
Hudson, Carrol D., Los Angeles, Calif.
Ingraham, Dwight M., Philadelphia, Pa.
Jablonski, Henry A., New York, N. Y.
Jackson, Dugald C., Jr., Columbia, Mo.
James, George I., Boston, Mass.
Janes, Leonard R., Cambridge, Mass.
Jennings, Frank B., Brooklyn, N. Y.
Johnson, Anders V., Malden, Mass.
Johnson, Elmer D., Pittsburgh, Pa.
Johnson, Ivan T., New York, N Y.
Johnson, Olan C., Chicago, Ill.
Johnson, Uno, Brooklyn, N. Y.
Jones, Erle M., Toronto, Ont.
Jones, John C., Cambridge, Mass.
Jones, Paul A., Washington, D. C.
Jones, William B., Pittsburgh, Pa.
Kane, Edward W., Milwaukee, Wis.
Keebler, Howard N., Norwood, Pa.
Keith, Alfred S., Pittsburgh, Pa.
Kendall, Allen B., Niagara Falls, N. Y.
Kietzman, William A., (Member) Philadelphia, Pa.
Klippel, Earl F., Bethlehem, Pa.
Kline, Elmer E., Cincinnati, Ohio
Knaell, Kenneth K., Charleroi, Pa.
Knoerr, Rudolph R., Lynn, Mass.
Knox, Raymond S., Long Branch, N. J.
Koenitz, Arthur C., (Member), New York, N. Y.
Kratzer, Joseph B., Meridian, Miss.
Laing, Sterling D., Moline, Kansas
Lajoie, George A. L., Montreal, Que.
Lake, Marshall E., Charlotte, N. C.
Lambert, Kenneth B., New York, N. Y.
Larom, Augustus P., New York, N. Y.
Larson, Ludvig C., Minneapolis, Minn.
Laurence, Eugene C., Belleville, N. J.
Lemen, Foster M., Delta, Iowa
Levy, Benjamin, Newark, N. J.
Lewelling, Raymond, Los Angeles, Calif.
Lewis, Amos L., Heldenville, Okla.
Lewis, Thomas P., Chicago, Ill.
Little, H. Boyd, Toronto, Ont.
Littman, Lawrence, Bessemer, Ala.
Lumley, Charles S., Newark, N. J.
Magann, Joseph W., Madison, Wis.
Mallory, Frank D., Jr., Dallas, Texas
Maney, Wallace L., Schenectady, N. Y.
Manning, Allen M., Portland, Ore.
Marbury, Ralph E., E. Pittsburgh, Pa.
McCarty, Robert S., Pittsburgh, Pa.
McConnell, Price, Anaconda, Mont.
McDonald, Cyril G. H., Schenectady, N. Y.
McMillan, James S., St. Paul, Minn.
McPherson, William B., St. Paul, Minn.
Melville, Samuel P., Boston, Mass.
Mercer, William H., Camden, N. J.
Merriman, Arthur G., W. Lafayette, Ind.
Miszkiel, Victor S., Ashley, Pa.
Mitchell, Chester F., Chicago, Ill.
Mockridge, Charles C., Dover, N. J.
Moesel, Ernest, New York, N. Y.
Moeslin, Edward D. W., New York, N. Y.
Moesta, Frederick E., Cleveland, Ohio
Monahan, Harry W., Ft. William, Ont.
Montague, Benjamin F., Charleston, W. Va.
Morris, Adolph F., Bethesda, Md.
Morse, Charles A., Jr., Cambridge, Mass.
Moss, Sidney W., (Member), New York, N. Y.
Nakamura, Jisuke, E. Pittsburgh, Pa.
Nevins, Ben R., Philadelphia, Pa.
Nigosiam, N. A., Akron, Ohio
Novak, Joe J., Chicago. Ill.
Oliver, J. Guy, Raleigh, N. C.
Olmedo, Hector H., Milwaukee, Wis.
Otten, Harry C., New York, N. Y.
Otting, Bernard, Cincinnati, Ohio
Outhwaite, Frank H., New York, N. Y.
Overstreet, Frank A., Grace, Idaho
Parker, Edward M., Mt. Vernon, N. Y.
Pease, Harold C., Cleveland, Ohio
Peaslee, William E., Washington, D. C.
Pendleton, Arvid M., Washington, D. C.
Peoples, Robert E., New York, N. Y.
Perry, Charles H., Cincinnati, Ohio
Pfromm, Conrad W., Hazelton, Pa.
Pirtle, James L., New York, N. Y.
Pohja, Harold W., Pittsburgh, Pa.
Poland, Frank F., Baltimore, Md.
Porter, George McC., Pittsburgh Pa.
Potter, Frank R., (Member), St. Louis, Mo.
Powell, George A., Schenectady, N. Y.
Powell, William H., Waterbury, Conn.
Preston, Jack D., Cambridge, Mass.
Pritchard, Clarence W., Washington, D. C.
Rathgeber, Mortimer D., Washington, D. C.
Raymond, Charles S., Schenectady, N. Y.
Rayner, Reid L., E. Lansing, Mich.
Redfern, Hazen G., Dinubar, Calif.
Reed, Linwood E., Washington, D. C.
Reynolds, Foster R., Kingston, Pa.
Rickerd, Cecil W., Peekskill, N. Y.
Robertson, William E. G., Toronto, Ont.
Robins, Orrin A., Columbus, Ohio
Roehrig, Frederick A., Pittsburgh, Pa.
Rogers, Warren A., Brooklyn, N. Y.
Roitburd, Jack R., New York, N. Y.
Rosebrugh, David W., Toronto, Ont.
Rosenbach, Samuel, Pittsburgh, Pa.
Ross, Bryon A., Hazelton, Pa.
Salter, Ernest H., W. Lafayette, Ind.
Samborn, Edgar F., Portsmouth, Va.
Sanderson, George E., Newark, N. J.
Sanford, William J., Camaguey, Cuba
Schauer, William, Pittsburgh, Pa.
Schippel, Walter H., Montreal, Que.
Schrage, Charles T., Chicago, Ill.
Schramm, Fred W., St. Louis, Mo.
Schaumacher, Harry E., New York, N. Y.
Seddon, Richard I., Joliet, Ill.
Seidman, Louis B., Brooklyn, N. Y.
Sessions, Robert C., Cleveland, O.
Shanahan, Oliver J., Pittsburgh, Pa.
Shutts, Walter L., Pittsburgh, Pa.
Silldorff, Henry C., Newark, N. J.
Sinex, Reuben T., Seattle, Wash.
Smith, Arthur B., St. Johns, N. F.
Smith, Aubrey, Schenectady, N. Y.
Smith, Bernard, Fayetteville, Ark.
Smith, Frank V., E. Pittsburgh, Pa.
Smith, Frederick J., Toronto, Ont.
Smith, Russell H., Stratford, Conn.
Smith, Walter F., Jr., New York, N. Y.
Smith, Wilbert H., New York, N. Y.
Snider, William H., Davenport, Iowa
Smith, William M., Jr., Washington, D. C.
Sonkin, David, New York, N. Y.
Spooner, Howard M., Newark, N. J.
Spracklen, Emery E., Alliance, Ohio
Spraker, Joseph G., Washington, D. C.
Stanger, Edward A., Montreal, Que.
Stansbury, William F., Washington, D. C.
Steinberg, John C., New York, N. Y.
Steiner, Landrie M., Washington, D. C.
Stewart, Malcolm G., Montreal, Que.
Stromberg, Petter Johan, (Member), Toronto, Ont.
Sumpter, John, (Member), Minneapolis, Minn.
Sun, Kus-Feng, W. Lynn, Mass.
Thakkur, Khimji B., Cambridge, Mass.
Thomas, Charles A., Washington, D. C.
Thompson, Albert V., San Francisco, Calif.
Thompson, Francis R., Pittsburgh, Pa.
Thor, Berg V., E. Pittsburgh, Pa.
Townsend, Henry W., Kansas City, Mo.
Trevett, Harold N., Troy, N. Y.
Tubbs, Lester G., E. Pittsburgh, Pa.
Tugendhat, G. Robert, New York, N. Y.
Tuska, Clarence D., Hartford, Conn.
Van Ark, James F., Chicago, Ill.
Van Gorder, Courtland T., Milwaukee, Wis.

Underhill, John V., Glenwood, N. Y.
Urban, Stephen, Jr., Perth Amboy, N. J.
Van Arsdel, Ernest, Indianapolis, Ind.
Vander, William C., New Bedford, Mass.
Van Ness, Bartow, Jr., Baltimore, Md.
Venturine, Julian B., Linnton, Ore.
Vogel, David, New York, N. Y.
Vorhes, Harold R., San Francisco, Calif.
Walter, Gilbert P., Washington, D. C.
Warren, Claude A., Portland, Ore.
Washington, Bowden (Member) New York, N. Y.
Watkins, Willis W., E. Pittsburgh, Pa.
Watt, Simpson, New York, N. Y.
Way, Howard E., Washington, D. C.
Webb, John K., Cleveland, Ohio
Webb, William L., Schenectady, N. Y.
Weigel, Frederick A., Lynn, Mass.
Weikel, William S., Schenectady, N. Y.
Weiss, W. Robinson, Denver, Colo.
West, Charles R., Philadelphia, Pa.
Westerlund, George E., Brooklyn, N. Y.
Wetsten, Ralph S., Newark, N. J.
Whelen, Morland P., Toronto, Ont.
Whitford, Ralph A., Schenectady, N. Y.
Whitmore, Harold B., Washington, D. C.
Williams, Allison R., (Member) Yazoo City, Miss.
Williams, David, New York, N. Y.
Willoughby, Thomas S., Boston, Mass.
Wilson, Allan, Washington, D. C.
Wilson, Arthur S., Hamilton, Ont.
Wilson, Elmer J., W. Lynn, Mass.
Wilson, J. M., Hinton, W. Va.
Winckler, George A., Worcester, Mass.
Winterhalter, T. S., Bayonne, N. J.
Woellert, Lester N., Milwaukee, Wis.
Wolf, Sidney K., E. Pittsburgh, Pa.
Wood, Carl E., Deer Lodge, Mont.
Woodruff, Walter W., Washington, D. C.
Woodzelle, Guy W., Cicero, Ill.
Worcester, Dean K., New York, N. Y.
Wright, Claude B., Pittsburgh, Pa.
Wright, William H., Washington, D. C.
Yarvots, Evart, New York, N. Y.
Young, Philip C., Hamilton, Ont.
Youngstrom, Nels C., Potsdam, N. Y.
Zimmerman, James E., Milwaukee, Wis.
Total 343

Foreign

Egiazaroff, John B., (Member), Petrograd, Russia
Ferguson, Samuel, (Member), Manchester, Eng.
Garrett, Percival T., Melbourne, Aus.
Martin, Geoffrey E., Bombay, India
Mowdawalla, F. N., Bombay, India
Owen, Harry, (Member), Honduras, C. A.
Pollard, Thomas R., Christchurch, N. Z.
Roy, Surendra K., (Member), Jamshedpur, India
Wright, Ratcliffe, Buenos Aires, S. A.
Total 9

STUDENTS ENROLLED NOVEMBER 10, 1922

15400 Connell, Douglas J., Lafayette College
15401 Rice, Cortis N., Jr., Worcester Polytechnic Institute
15402 Coronado, Charles A., Ohio State Univ.
15403 Alford, Charles M., Lehigh University
15404 Alwine, Charles E., Lehigh University
15405 Baker, Ernest W., Lehigh University
15406 Bridegam, Warren J., Lehigh University
15407 Degnan, James M., Jr., Lehigh University
15408 Foster, Arthur L., Lehigh University
15409 Gerhart, Paul L., Lehigh University
15410 Grim, James S., Jr., Lehigh University
15411 Leice, Donald C., Lehigh University
15412 Levy, Bertram R., Lehigh University
15413 Master, Warren S., Lehigh University
15414 Miller, William H., Lehigh University
15415 Morgan, G. Dodson, Lehigh University
15416 Paxton, George B., Lehigh University
15417 Rice, Janvier M., Lehigh University
15418 Ritter, Ralph S., Lehigh University
15419 Robinson, Edmund L., Lehigh University
15420 Sattenstein, Sidney L., Lehigh University
15421 Aikins, Nelson B., University of Maine
15422 Bohrmann, William J., Jr., Lafayette Coll.
15423 Gaede, George F., Lafayette College
15424 Lorje, Herman, University of Colorado
15425 Diers, Frank Jr., University of Illinois
15426 Dixon, Hubert T., University of Illinois
15427 Guenther, Raymond, University of Illinois
15428 Hahn, Herman E., University of Illinois
15429 Knight, Max H., University of Illinois
15430 Hart, Morris B., University of Illinois
15431 Robinson, George W., University of Illinois
15432 Wallin, Marino R., University of Illinois
15433 Whelan, Dow Orland, University of Illinois
15434 Robertson, Gordon L., Virginia Military Institute
15435 Baty, Lawrence E., Kansas State Agricultural College
15436 Henderson, Fred E., Kansas State Agricultural College
15437 Johnson, Vernon L., University of Maine
15438 Anderson, Louis I., University of Nebraska
15439 Welch, Harold E., University of Maine
15440 Welsh, William E., Lafayette College
15441 Dow, Lowell J., University of Maine
15442 Stewart, Donald McL., Carnegie Institute of Technology
15443 Hanstein, Henry B., Brooklyn Poly. Inst.
15444 Real, John A., University of Colorado
15445 Smith, Joe L., Kansas State Agri. Coll.
15446 Sweet, Everett L., Mass. Inst. of Tech.
15447 Conover, Lawrence, Lafayette College
15448 Steele, Joseph H., Bucknell University
15449 Gehring, W. George, Bucknell University
15450 Hazen, Leonard C., Penn. State College
15451 Palmer, Gail W., University of Wisconsin
15452 Rosenwald, Otto H., University of Maine
15453 Abbott, Ernest J., University of Michigan
15454 Alexander, Robert W., Univ. of Michigan
15455 Bollinger, N. H., University of Michigan
15456 Brice, William A., University of Michigan
15457 Bruch, Ralph R., University of Michigan
15458 Discher, Elton M., University of Michigan
15459 George, Howard C., University of Michigan
15460 Glass, David H., Jr., Univ. of Michigan
15461 Kingdon, Howard F., Univ. of Michigan
15462 Leingang, William C., Univ. of Michigan
15463 Moreland, Edwin S., Univ. of Michigan
15464 Piper, William J., Univ. of Michigan
15465 Sandorf, Irving J., University of Michigan
15466 Tsou, Tsong Yua, University of Michigan
15467 Tuttle, James H., University of Michigan
15468 Tynes, John P., University of Michigan
15469 Barnez, Randal P., University of California
15470 Barr, Rowland W., University of California
15471 Bass, Oswald B., University of California
15472 Berry, Robert H., University of California
15473 Best, Albert O., University of California
15474 Blocksom, Franklin C., Univ. of California
15475 Chubb, Theodore M., Univ. of California
15476 Cole, Donald S., Univ. of California
15477 Delius, Herbert A., Univ. of California
15478 Dryer, Elbert O., Univ. of California
15479 Ellison, Milton A., University of California
15480 Folsom, Leon T., University of California
15481 Fong, Wah B., University of California
15482 Geiser, Carl Y., University of California
15483 George, Cyril S., University of California
15484 Gilmartin, William H., Univ. of California
15485 Hadley, Paul T., Univ. of California
15486 Harper, Paul F., University of California
15487 Holden, John A., University of California
15488 Isham, Carlton G., University of California
15489 Laughlin, James D., Univ. of California
15490 Martin, William H., Univ. of California
15491 McCauley, Charles, Jr., Univ. of Calif.
15492 Morgan, John L., Univ. of California
15493 Mowry, Charles E., Univ. of California
15494 Nelson, Clarence Wm., Univ. of California
15495 Raab, Harry J., Univ. of California
15496 Richey, Robert R., Univ. of California
15497 Russell, Clifford A., Univ. of California
15498 Westcott, Stanley B., Univ. of California
15499 Zimmerman, Andrew G., Univ. of Calif.
15500 Horowitz, Nathan, Cooper Union
15501 Wallis, Ralph J., New Hampshire State College
15502 Maxwell, Weyman E., New Hampshire State College
15503 McProud, Charles G., Calif. Inst. of Tech.
15504 Scaron, Juan P., University of Notre Dame
15505 Meaker, O. Phelps, Mass. Inst. of Tech.
15506 Reynolds, Forrest, Kansas State Agri. Coll.
15507 Bivens, Bert, Kansas State Agri. College
15508 Misegades, Edgar L., Kansas State Agricultural College
15509 Melcher, Henry J., Kansas State Agricultural College
15510 Lockhart, William K., Kansas State Agricultural College
15511 Lentz, J. Clyde, Kansas State Agri. Coll.
15512 Lydick, Clarence J., Kansas State Agricultural College
15513 Lasher, George W., New York Elec. School
15514 Mosley, John E., Alabama Poly. Institute
15515 Dickinson, Robert C., Alabama Poly. Inst.
15516 Holman, Frank L., Alabama Poly. Inst.
15517 Naftel, Bolling K., Alabama Poly. Inst.
15518 Williams, Horace G., Alabama Poly. Inst.
15519 Kling, August J., Alabama Poly. Inst.
15520 Johnson, Oren, Alabama Poly. Inst.
15521 Antz, Joseph L., Cornell University
15522 Gilchrist, John M., Cornell University
15523 Michel, Achilles, Cornell University
15524 Demerec, Mary Z., Cornell University
15525 Mera, Jose R., Cornell University
15526 Story, Theodore H., Cornell University
15527 Rizzo, Francis, Cornell University
15528 Lippincott, Charles D., Cornell University
15529 Nakamoto, Hayato, Cornell University
15530 Bibbins, George S., Cornell University
15531 Seagers, Paul W., Cornell University
15532 Winograd, Harold, Cornell University
15533 Orcutt, Howard S., Cornell University
15534 Miller, E. Parker, Cornell University
15535 Brown, Jesse E., Cornell University
15536 Brown, Carl C., Cornell University
15537 Goodman, Lewis O., Cornell University
15538 LeRoy, Claude A., Cornell University
15539 Baumgarten, Adolph J., Cornell University
15540 Wieters, Charles, Cornell University
15541 Cooper, John B., Cornell University
15542 Anderson, Eric G., University of Idaho
15543 Landdenberger, William H., Pennsylvania State College
15544 Olson, Harold A., Syracuse University
15545 Gifford, Gordon E., Syracuse University
15546 Ahn, Harold D., Syracuse University
15547 Greenleaf, Ned P., Syracuse University
15548 Hummel, John G., Syracuse University
15549 Liedy, Henry K., Syracuse University
15550 Huntley, Clifford E., Syracuse University
15551 Abbott, Henry H., Ohio State University
15552 Ayers, Robert C., Ohio State University
15553 Bentzon, Carlos E., Ohio State University
15554 Brixner, Frederick W., Ohio State Univ.
15555 Carter, Rolla N., Ohio State University
15556 DeLong, Darrol F., Ohio State University
15557 Dickey, Albert W., Ohio State University
15558 Eppley, Ivan C., Ohio State University
15559 Ferguson, Edward F., Ohio State Univ.
15560 Fetterman, Frank H., Ohio State Univ.
15561 Fitzgerald, Joseph W., Ohio State Univ.
15562 Greer, Carroll I., Ohio State University
15563 Hill, Colven B., Ohio State University
15564 Jacquot, Lee R., Ohio State University
15565 Johns, George J., Ohio State University
15566 Kellogg, William McK., Ohio State Univ.
15567 Kerstetter, John H., Ohio State Univ.
15568 Lewis, Harold P., Ohio State University
15569 Long, James W., Ohio State University
15570 Lyon, Sherman B., Ohio State University
15571 Metters, Thomas H., Ohio State University
15572 Rahrig, Gilbert O., Ohio State University
15573 Rearden, Robert A., Ohio State University
15574 Richards, Edwin E., Ohio State University
15575 Santini, Danielo, Ohio State University
15576 Schmidt, Eugene, Ohio State University
15577 Smith, Floyd F., Ohio State University
15578 Smith, Lucian B., Ohio State University
15579 Tuura, Niilo E., Ohio State University
15580 Van Sweringen, Harold D., Ohio State University
15581 Wheaton, Soren B., Ohio State University
15582 Williamson, Robert B., Ohio State Univ.
15583 Wise, Elmer C., Ohio State University.
15584 Zimmer, Frederic M., Ohio State Univ.
15585 Reilly, Francis P., Marquette University
15586 Johnson, J. O., Marquette University
15587 Hill, Austin S., Marquette niversity

15588 Keltz, Merrill F., Marquette University
15589 Coughlin, William E., Marquette Univ.
15590 Anderzak, Ray, Marquette University
15591 Pryor, William E., Marquette University
15592 Rex, Harold B., Mass. Inst. of Tech.
15593 Rosen, Charles F., Lowell Institute
15594 Parks, Marvin B., Bliss Electrical School
15595 Kidder, Allan H., Mass. Inst. of Tech.
15596 Carr, John California Inst. of Tech.
15597 Little, Fred G., California Inst. of Tech.
15598 Maltby, Clifford M., California Inst. of Technology
15599 Parker, Cecil N., California Inst. of Tech.
15600 Walker, Joseph H., Jr., Calif. Inst. of Tech.
15601 Gould, Albert S., Calif. Inst. of Tech.
15602 Harries, David G., Jr., Calif. Inst. of Tech.
15603 Ewbank, Eric E., A. & M. College of Texas
15604 Sharp, C. B., A. & M. College of Texas
15605 Harold, Arbucke A., Purdue University
15606 Churchill, Homer, Purdue University
15607 Ridgley, Charles H., Purdue University
15608 Boyce, Harry A., Jr., Purdue University
15609 Cramer, Lora P., Purdue University
15610 McIlvaine, Oron T., Purdue University
15611 Kahl, Herman C., Purdue University
15612 Williams, Roy B., Purdue University
15613 Reynolds, Rex L., Purdue University
15614 Rauth, Adolph W., Purdue University
15615 Ramm, Aubrey G., University of Wash.
15616 MacKenzie, H. A., University of Wash.
15617 McNeill, Harold E., University of Wash.
15618 Walker, Robert A., University of Wash.
15619 Fitzpatrick, George Wm., Univ. of Wash.
15620 Kelsey, Henry G., University of Wash.
15621 German, Coenelio, University of Wash.
15622 Noel, Lionel S., University of Wash.
15623 Smith, William R., New York Elec. School
15624 Sweeney, C. Porter, Bliss Elec. School
15625 Reese, Thomas L., Tri-State College of Engineering
15626 Reed, Charles L., Jr., Mass. Inst. of Tech.
15627 Lamborn, Richard L., Mass. Inst. of Tech.
15628 Davidson, Harry L., Kansas State Agricultural College
15629 Messenheimer, Alva E., Kansas State Agricultural College
15630 Yoder, Raymond S., Kansas State Agricultural College
15631 Lingelbach, George D., Kansas State Agricultural College
15632 Amos, Earl B., Kansas State Agricultural College
15633 Copeland, M. J., Kansas State Agri. Coll.
15634 Johnson, Carl D., Kansas State Agri. Coll.
15635 Garrett, John LaRue, Pennsylvania State College
15636 Camey, John S., Pratt Institute
15637 Conti, Amando J., Jr., University of Maine
15638 Moore, Carlton H., Tri-State Coll. of Engg.
15639 Chaplin, Byron L., Penn. State College
15640 de Sautos, Angel, New York Elec. School
15641 Shore, Herbert K., State Univ. of Iowa
15642 Rasmussen, Clarence F., Univ. of Wis.
15643 Smith, Donald R., Bucknell University
15644 Yarborough, Morris N., Virginia Military Institute
15645 Werhan, Floyd L., Kansas State Agri. Coll.
15646 Reed, Walter H., Kansas State Agri. Coll.
15647 Casto, J. Harold, Oregon Agri. Coll.
15648 Deichman, Charles L., Oregon Agri. Coll.
15649 Murton, Jack H., Oregon Agri. Coll.
15650 Moor, Percy W., Pennsylvania State Coll.
15651 Fleming, Frank L., Univ. of Pennsylvania
15652 Allegeyer, Walter F., New York Electrical School
15653 Roth, Jesse E., University of Kansas
15654 Eyer, Donald B., University of Kansas
15655 Harris, Clarence A., University of Kansas
15656 Anderson, William B., University of Kansas
15657 Huffman, Harold F., University of Kansas
15658 Woodcock, Randall W., Univ. of Kansas
15659 Philleo, Edward W., University of Kansas
15660 Freyler, Frank R., University of Kansas
15661 Treu, William L., University of Kansas
15662 McCauley, Albert D., University of Kansas
15663 Cohn, Byron S., University of Kansas
15664 Havenhill, Marshall A., Univ. of Kansas
15665 Wilkins, Harry, University of Kansas
15666 Aubel, Paul K., Johns Hopkins University
15667 Steinberg, Benj. B., Brooklyn Poly. Inst.
15668 Liu, Hsiao-Ching, Mass. Inst. of Tech.
15669 Lehr, George W., Pennsylvania State Coll.
15670 Crane, Robert H., Penn. State College
15671 Parker, Leonard C., Oregon Agri. Coll.
15672 Gillam, Herman P., Oregon Agri. College
15673 Little, Thomas G., Oregon Agri. College
15674 Lentz, Leon, Jr., Pennsylvania State Coll.
15675 Brown, Harold K., Iowa State College
15676 Gobeli, Ralph R., Iowa State College
15677 Halbasch, Gerald K., Iowa State College
15678 White, Edward, Iowa State College
15679 Talsma, Clarence, Iowa State College
15680 O'Day, John H., Iowa State College
15681 King, Herberg, Jr., Iowa State College
15682 Joslin, Murray, Iowa State College
15683 Delahooke, Tracy E., Iowa State College
15684 Benesh, Edward J., Iowa State College
15685 Hogue, William M., Iowa State College
15686 Christensen, Walter J., Iowa State College
15687 McAdams, Ray M., Iowa State College
15688 Fullerton, William O., Iowa State College
15689 Bode, R. H. William, Iowa State College
15690 Scheldorf, Marvel W., Iowa State College
15691 Keith, Fay E., Iowa State College
15692 Pagel, Arthur W., Iowa State College
15693 Jennings, Guy A., Iowa State College
15694 Iseminger, Carleton R., Iowa State College
15695 Mueller, Mark D., Iowa State College
15696 Fowler, Eugene B., Iowa State College
15697 Locker, Leo L., Iowa State College
15698 Wolters, A. E., Iowa State College
15699 Terrance, Emmet H., McGill University
15700 Knight, Elmer M., University of Virginia
15701 Nottingham, Frank O., Jr., Univ. of Va.
15702 Abbott, William M., Univ. of Virginia
15703 Shelhorse, Albert W., Univ. of Virginia
15704 McDavitt, Marcellus B., Univ. of Virginia
15705 Henderson, Thomas H., University of Va.
15706 Robinson, Carl R., University of Virginia
15707 Hsu, Hou-Yu, Mass. Inst. of Technology
15708 Harlow, James H., Univ. of Maryland
15709 Greene, Frank M., Brooklyn Poly. Inst.
15710 Bisesi, Joseph L., Univ. of Illinois
15711 Fawcett, O. Emmett, Univ. of Illinois
15712 Patterson, Arthur K., Penn. State College
15713 Kraus, Constantine R., Penn. State Coll.
15714 Hart, Roland R., Bliss Electrical School
15715 Holmes, Ralph S., University of Nebraska
15716 Sprinkle, Herbert O., Carnegie Inst. of Technology
15717 Dilberger, Harold A., Oregon Agri. Coll.
15718 Johnson, Conrad H., Kansas State Agricultural College
15719 Ward, I. Raymond, Kansas State Agricultural College
15720 Prescott, Russell M., Kansas State Agricultural College
15721 Phillips, Stanley N., Univ. of Kansas
15722 Mowry, Churchill H., Rhode Island State College
15723 Campbell, Arch S., Case School of Applied Science
15724 Charles, Dwight M., Case School of Applied Science
15725 Dorn, B. Herman, Case School of Applied Science
15726 Kunz, Alfred F., Case School of Applied Science
15727 Shaffer, Ralph, Bliss Electrical School
15728 Chandler, Myron K., Mass. Inst. of Tech.
15729 Ede, Frank C., Mass. Inst. of Tech.
15730 Brockerman, Herman, Ohio Northern University
15731 Halligan, Clair Wm., Bucknell University
15732 Gibble, S. Lloyd, Pennsylvania State Coll.
15733 Bowers, Delbert L., Penn. State College
15734 Davis, C. Vernoy, Penn. State College
15735 Weser, Norbert C., Carnegie Inst. of Tech.
15736 Warshaw, Bernard S., Drexel Institute
15737 Roberts, George B., Drexel Institute
15738 Young, Thomas H., Jr., Sheffield Scientific School
15739 Bricker, George W., Jr., Mass. Inst. of Tech.
15740 Hibbard, Charles J., Jr., Cornell University
15741 Otto, Edward A., Cornell University
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15743 McKeon, John B., Cornell University
15744 Davis, Dan B., Cornell University
15745 Weiner, Louis, Cornell University
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15747 Gulp, Frederick G., Cornell University
15748 Pfleger, Kenneth W., Cornell University
15749 Knandel, George J., Cornell University
15750 McCracken, Henry J., Cornell University
15751 Brainard, D. Edward, Cornell University
15752 Cheng, Wan Chung, Cornell University
15753 Artamouff, George L., Yale University
15754 Halpin, Lewis C., Tri-State College
15755 Dreyfus, James, Brooklyn Poly. Inst.
15756 Sieh, George J., Murray Hill Evening Trade School
15757 Chesnut, Frank T., Univ. of Maryland
15758 Wappler, Frederick C., Mass. Inst. of Tech.
15759 Sklaire, Harris, Sheffield Scientific School of Yale Univ.
15760 Brown, Earle A., Sheffield Scientific School of Yale Univ.
15761 Lee, Shee Mou, Harvard University
15762 Crotty, Harold F., Mass. Inst. of Tech.
15763 Flynn, Henry, Mass. Inst. of Tech.
15764 Mancini, Frank G., Penn. State College
15765 Beer, Paul G., University of Wisconsin
15766 Bradshaw, Dennis E., Virginia Poly. Inst.
15767 Fishbeck, Lloyd, Univ. of Michigan
15768 Richards, Kenneth W., Univ. of Michigan
15769 Mears, Gilbert E., Univ. of Michigan
15770 Smith, Earl J., Univ. of Michigan
15771 Tang, Kwan Y., Univ. of Michigan
15772 Johnson, James B., University of Michigan
15773 Crans, Peter W., University of Michigan
15774 Apted, Durfee B., University of Michigan
15775 Serra, Martin J., University of Michigan
15776 Weitzman, Harry A., University of Mich.
15777 Chatterton, Eugene, Univ. of Michigan
15778 Baum, Edwin K., Stanford University
15779 Ault, Dean D., University of Arkansas
15780 Whitlow, George S., University of Arkansas
15781 Huggins, L. Gale, University of Arkansas
15782 Hoelz, Alfred N., University of Wisconsin
15783 Humphrey, Barney E., Univ. of North Carolina
15784 Wixson, Lloyd H., Univ. of Arizona
15785 Cushing, Robert M., Univ. of Arizona
15786 Vopatek, Stephen H., Univ. of Arizona
15787 Erb, Merion J., Univ. of Arizona
15788 Smith, Theodore L., Sheffield Scientific School of Yale Univ.
15789 Keller, Edward J., Drexel Institute
15790 Andem, Kenneth S., Mass. Inst. of Tech.
15791 Vaden, Thomas Hunt, Virginia Military Institute
15792 Rounds, Thomas E., Jr., Mass. Inst. of Tech.
15793 Sargent, John Carlton, Mass. Inst. of Tech.
15794 Gentry, Frank M., Mass. Inst. of Tech.
Total 395.

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Transformers.—Miniature bulletin 4045 describing distribution transformers in all standard ratings up to 200 kv-a. of the Allis-Chalmers Manufacturing Company, Milwaukee.

Bleeder Turbines.—A descriptive article on the history and theory of bleeder turbines by J. L. Moore, President, Moore Steam Turbine Corporation, Wellsville, N. Y.

Wire Charts and Tables.—Sag and tension charts and loading tables and wire tables for Aristos "Copperweld" wire and strand, are now available. Copper Clad Steel Company, Rankin, Pa.

Attachment Plugs and Accessories.—Catalog, 24 pp. Describes the complete line of flush devices, attachment plugs, circuit receptacles, etc., of the Arrow Electric Company, Hartford, Conn.

Motors.—Miniature bulletin 4043 describing type "AR" polyphase induction motors, ½ to 200 h. p.; and bulletin 4044 on type "E" direct-current motors. Allis-Chalmers Manufacturing Company, Milwaukee.

Thermostatic Relay Switch.—Bulletin, 4 pp. Describes a new type of switch for the thermostatic control of motors, electric heating units and other electrical circuits. Minneapolis Heat Regulator Company, Minneapolis.

Steel Sections.—Bulletin 143, 54 pp. Describes steel sections for overhead shafting layouts to support machinery, motors, transmission equipment, etc. Midwest Steel & Supply Company, 28 West 44th Street, New York, N. Y.

Drafting Room Supplies.—Catalog, 384 pp., cloth bound. Describes and illustrates a wide range of equipment and supplies for draftsmen and engineers. Blue print, drawing and tracing papers, drafting instruments, desks and boards, etc. New York Blue Print Company, 96 Reade Street, New York, N. Y.

Insulating Varnishes and Compounds.—Catalog, 48 pp. A comprehensive treatment of the requirements of insulating varnishes and the uses to which the many grades of this product may advantageously be put. Directions for the care of varnishes and compounds and the preparation of material for brush spraying or dipping, as well as draining and baking, are given, Sections are devoted to baking ovens and vacuum pressure impregnation. Illustrated by photographs and charts. The Sterling Varnish Company, Pittsburgh.

Radio Amplifying Transformer.—Bulletin 975. Describes the new type AF-6 Amertran audio-frequency amplifying transformer. The outstanding feature of the device is its amplifying power (38.6) and which it is claimed is maintained practically constant over the entire range of useful frequencies, thus reproducing the voice and music both as to volume and modulation as nearly perfect as is possible in radio reception. An interesting chart illustrating the audibility amplification of the Amertran, and musical scale, is contained in the bulletin. American Transformer Company, Newark, N. J.

NOTES OF THE INDUSTRY

Pure Carbon Company, Wellsville, N. Y.—Carbon Brushes. The H. M. Thomas Company, 616 Title Insurance Building, Los Angeles, and 708 Oakland Bank Building, has been appointed California sales representative.

Century Electric Company, St. Louis.—Word has been received that Mr. John Herget, Treasurer of this company, died on November 14, at the age of seventy-seven. He became connected with the Century Electric Company in 1904 and was very active in his position up to within a few days of his death. Mr. Herget was born in Hamburg, Germany, and with his parents came to this country in 1849. When he was twenty-one years of age he moved to St. Louis where he resided permanently.

Simplex Wire & Cable Company, Boston.—A branch office was established on November 1, in New York City at 120 West 32nd Street, with Joseph G. Brobeck as manager. Mr. Brobeck has been engaged in the sale of Simplex wires and cables in the New York territory for several years, previous to which he was connected with the Simplex sales organization at Boston for nineteen years.

Gibb Instrument Company.—Electric welding equipment. Announcement is made of the removal of the plant and offices from Detroit to Bay City, Michigan, effective December first. The new quarters of the company provide the greatly increased manufacturing facilities necessary to take care of a rapidly increasing business. For the past two years this company has concentrated on the development of automatic and semi-automatic arc, spot and seam welders.

The High Tension Company, 120 Broadway, New York.—was incorporated on October 23, 1922, with the following officers: Robert A. Sandt, President; G. V. Woody, Vice-President and S. V. V. Hoffman, Jr., Secretary and Treasurer. The new company is engaged in the manufacture of outdoor substation equipment and transmission line accessories, making a specialty of vertical air break switches, disconnecting switches, choke coils, bus supports, steel structures; seamless copper splicing sleeves, insulator clamps, transmission line hardware, and other electrical fittings.

Mutual Electric & Machine Company, Detroit.—At a recent convention of the salesmen of this company tests were conducted at the Congress Street substation of the Detroit Edison Company for the purpose of demonstrating the extreme sturdiness and entire safety of the "Bull Dog" Safety Switch. Factory and sales demonstrations, discussions of policies and other convention matters occupied the time of the sales force during the convention. The sale of the "Bull Dog" Safety Switch has been placed under a separate division in the Chicago territory, E. A. Printz, 1316 Manhattan Building, Chicago, in charge. The sale of open type knife switches, cutouts and lugs in the Chicago territory will continue to be directed by J. S. Jacobson, 627 West Jackson Boulevard, Chicago.

The Johns-Pratt Company, Hartford, Conn.—W. S. Gordon, for the past twelve years with the Molding Department of the Bakelite Corporation, has been appointed sales manager of the Molded Products Division of this company. Mr. Gordon's experience will be particularly valuable because of the completeness of the Johns-Pratt Company's manufacturing facilities, which include equipment for molding Bakelite, Condensite and Redmanol, as well as a number of other special compounds. Mr. Gordon will make his headquarters at the factory in Hartford.

George Saylor has been appointed western sales manager of the Electrical Division with headquarters at 36 So. Desplaines Street, Chicago, and L. F. Carleton as district sales manager, Electrical Division, with offices in the Boatmen's Bank Building, St. Louis.

Westinghouse Electric & Manufacturing Company, East Pittsburgh.—Contracts for power apparatus aggregating more than $3,500,000 have been received during the past month by the Power Department. This total business shows a marked increase in the total sales of previous months and indicates the trend toward normalcy in the electrical industry. Central station companies have been large contributors to this volume of business; new power stations are being erected by a number of public utilities and extensions are being made by others to take on new loads. A large part of the orders recently received have been from customers in this country, but at the same time the activity in the export field has not diminished. Business in Japan particularly, continues brisk due to the further purchase of equipment for power stations being built in connection with the proposed super-power system in that country.

"This wire fits like a nut on a bolt"

"It's right! *It goes in the space.* That's why I'm doing better work."

Acme Wire accounted for the sudden increase in this winder's production, and, what is more important, fewer rejections and better wound coils throughout. That was because Acme Wire is uniform, free from lumps and imperfections, speedy in winding, and really "*goes in the space.*"

Such instances are common; in fact, usual, when Acme Wire is used rather than inferior wire—bought on a price basis. For Acme Wire is made carefully—every step in the process is based on standards of performance in the buyer's winding room. From the very start of the Acme enterprise their strict adherence to quality standards has been notable in the industry.

Acme Wire—*it goes in the space.* There's magic in those words for the operator who no longer has to stop work to cut out poor wire, for the engineer who wants his specifications filled exactly, so that his coil can be built as he designed it, and for the Purchasing Agent who keeps in close touch with the Winding Room and knows that cheap wire does not always mean inexpensive coils.

Illustrated Catalog on Request to Engineers, Purchasing Agents, Executives and Operators.

THE ACME WIRE CO., New Haven, Conn.
NEW YORK CLEVELAND CHICAGO

Some Users of Acme Magnet Wire

Atwater Kent Mfg. Co.
Azor Motor Mfg. Co.
Century Electric Co.
Dayton Engineering Laboratories Co.
Delco-Light Co.
Diehl Mfg. Co.
Eisemann Magneto Corporation
Electric Specialty Co.
Electrical Products Mfg. Co.
Emerson Electric Mfg. Co.
Eureka Vacuum Cleaner Co.
Ford Motor Co.
General Radio Co.
Gray & Davis, Inc.
Holtzer-Cabot Electric Co.
Hoover Suction Sweeper Co.
Klaxon Co.
Robbins & Myers Co.
Sangamo Electric Co.
U. S. Auto Supply Co.
Westinghouse Elec. & Mfg. Co.
Willys Corporation
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Acme Wire Products

"Enamelite," plain enameled Magnet Wire; "Cottonite," Cotton-covered Enamelite; "Silkenite," Silk-covered Enamelite; Single and Double Cotton Magnet Wire; Single and Double Silk Magnet Wire. We also have a complete organization for the winding of coils in large production quantities.

Acme Electrical Insulations

Flexible Varnished tubing in all standard sizes and colors.

Acme Radio Specialties

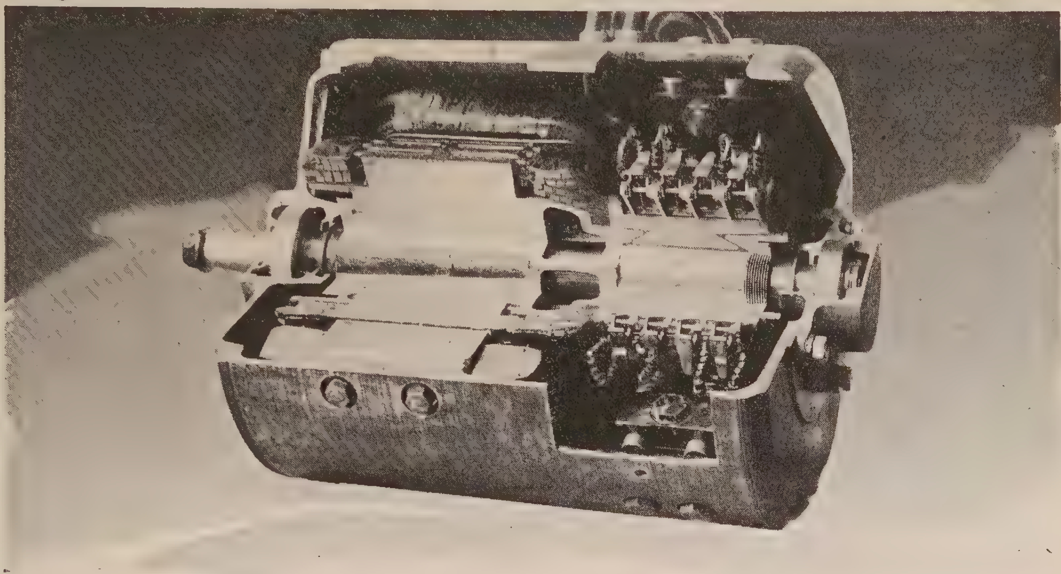
Audio Transformer windings.
Radio Frequency windings.
Magnet windings for Head Sets.
Enameled wire—especially the finest sizes, 40-44 B & S gauge.
Silk and cotton-covered magnet wire.
Enameled Aerial wire—single wire and stranded.

ACME

Acme Wire

"It goes in the space"

SKF



Ball Bearings on Motors of Limited Dimensions Permit Better Characteristics

WHERE the overall length of a motor of given capacity is limited by space restrictions, the space sacrificed for long bearings makes it necessary to employ a higher flux density in the iron structure than when short bearings are used.

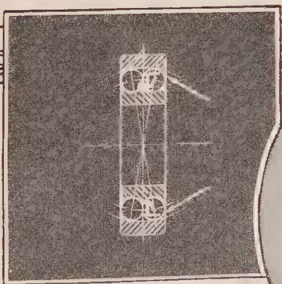
SKF marked self-aligning ball bearings, in saving 20 per cent of the overall length required where plain bearings are used, permit the designing engineer to utilize this space for increasing the capacity of the motor or decreasing the iron losses which are frequently so great as to materially restrict the time of continuous running at full load.

Other advantages which play an important part in motor performances are the elimination of frictional wear with resultant possibility of stripped armatures, and the exclusion of dust and grit from the bearings. Write for engineering details.

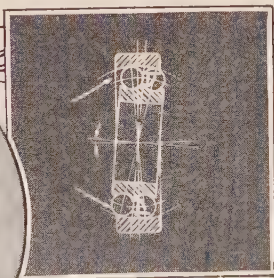
THE SKAYEF BALL BEARING COMPANY

Supervised by SKF INDUSTRIES, INC., 165 Broadway, New York City

780



Normal View



Deflected View

BALL BEARINGS

The Highest Expression of the Bearing Principle

THE COMPOUND WE USE

ALL compounds alike? Most decidedly *not!*

Between a cheap, ready-made mixture and that which we use in our weatherproof wire there is a big difference.

So big, in fact, that *we make our own compound* in order to be certain of achieving that difference.

Only the highest-grade impregnating materials are used in our compound; and only highly skilled mixers are permitted to work out its formula.

The result, we believe, is:

> The best impregnating compound used today—one which over a long term of years has met the most exacting heat and freezing tests, and which we believe will outlast all other compounds.

Large utility companies—those whose specifications are admittedly exacting and who demand the best, always—seldom re-order unless they are satisfied. Over a period of 15 years, we have sold millions of pounds of weatherproof wire to such companies.

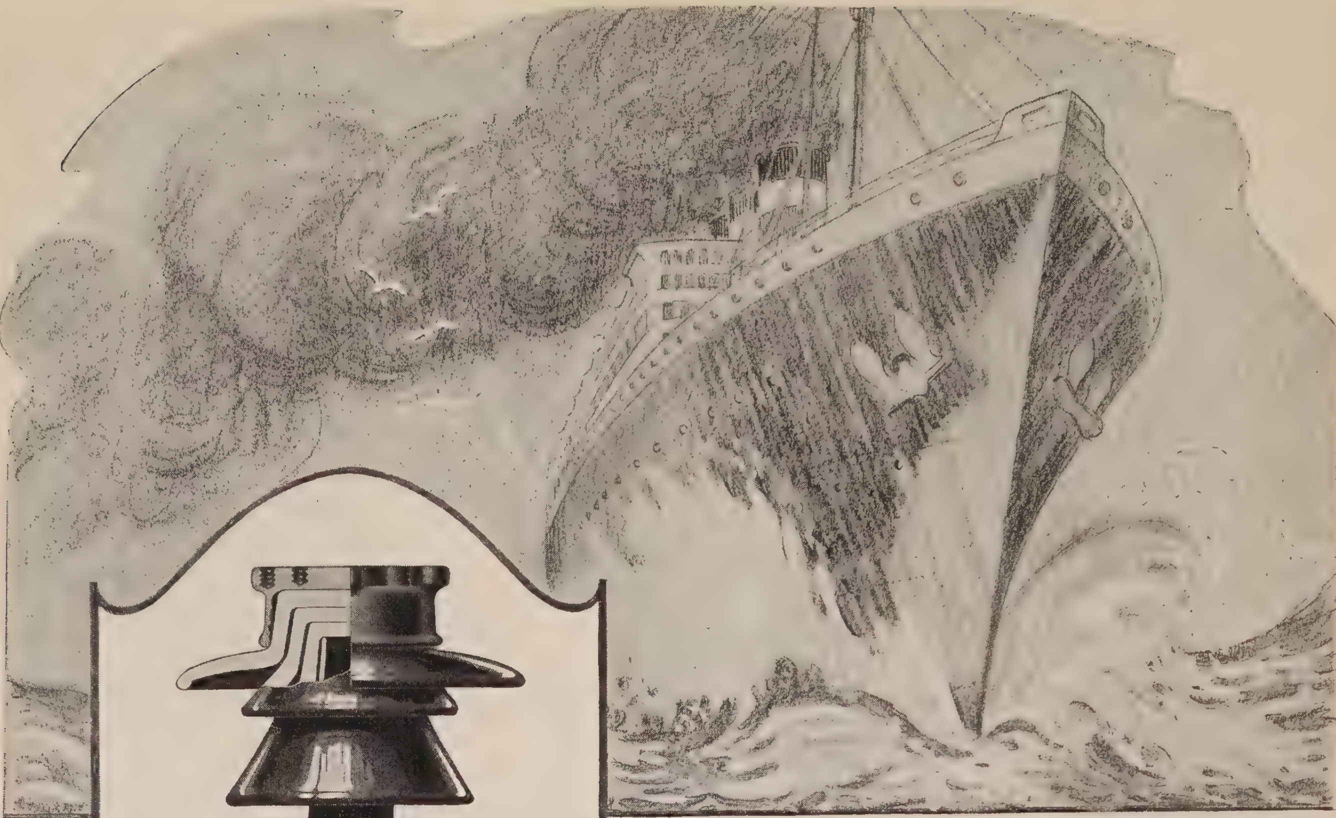
One of the reasons why many of them regard our weatherproof wire as the best and most economical wire to buy is to be found in the *quality* of our impregnating compound.

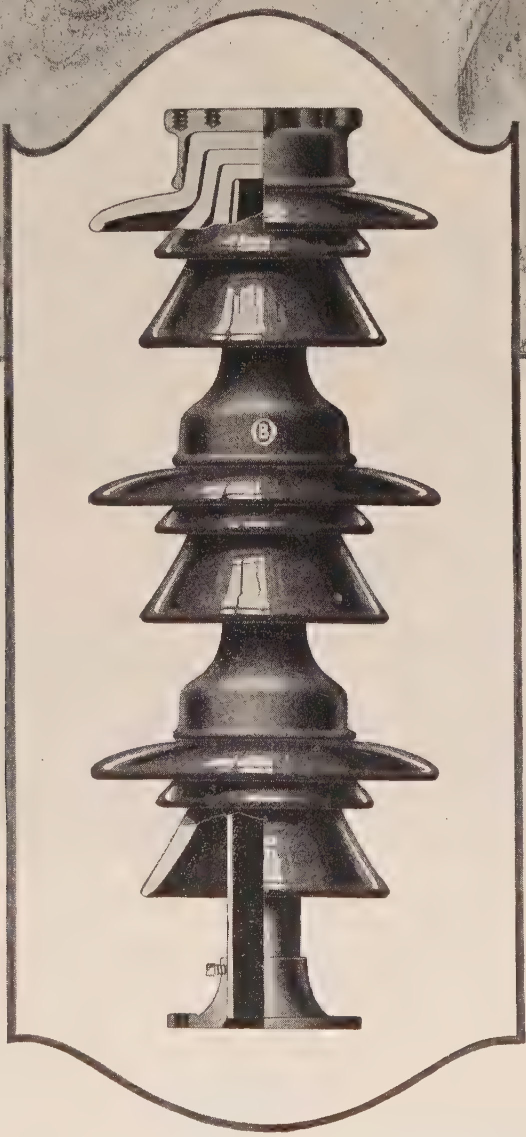
Mills, Bayway, N. J.

AMERICAN COPPER PRODUCTS CORPORATION
200 BROADWAY NEWYORK

Trade Mark

AMERICAN COPPER PRODUCTS CORPORATION





POWER DIRECTED

DOWN in the boilers of the great ocean liner is a powerful head of steam. But this stored up energy is useless until it is directed and applied to propellers and rudder. Then, it drives the ship on its course in spite of terrific onslaughts by wind and wave. Man-made power, directed, becomes more than a match for the boundless but unorganized force of the elements.

Every central station on the continent might have a maximum head of steam or a lake full of water in vain, if there was no way to transmit the power to the point where it was needed. But electric power can be transmitted—safely, cheaply and reliably.

In the direction of electric power, from the point where it is produced to the point where it is used, O-B Insulators aid. They insulate and support the intricate current-carrying structure in the station and the long miles of transmission line. By their mechanical strength and their electrical reliability O-B Insulators help to make available the energy which the Central Station produces.

O-B Designs *Improve* the Lines

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Products: Trolley Material, Rail Bonds, Electric Railway Car Equipment, High Tension Porcelain Insulators, Third Rail Insulators

The Genuine!

There is only one "Guaranteed Penetration Process" - its "the P & H". It guarantees- in writing - a **full one half inch** uniform penetration throughout the ground line area.

A written guarantee goes with every shipment of "P & H Guaranteed Penetration Process" poles agreeing to refund the butt-treating price on any pole that does not have the full specified half-inch penetration.

The "P & H" Guaranteed Penetration Process

gives you absolutely certain results no guesswork. For the most reliable pole service - for the longest pole life - insist on the genuine "P & H"

We can fill any pole needs - for Butt-Treated and untreated Northern White and Western Red Cedar poles - or for any form of Butt-Treatment.

Prompt Shipment assured by the convenient location of our yards in the North Central and Western States.

Our interesting folder on the Butt-Treatment of cedar poles will tell you the why and wherefor of the "P & H Guaranteed Penetration Process." Write for a copy.

"P & H" Guaranteed Penetration Process Poles in lines of Chicago, North Shore and Milwaukee R. R.

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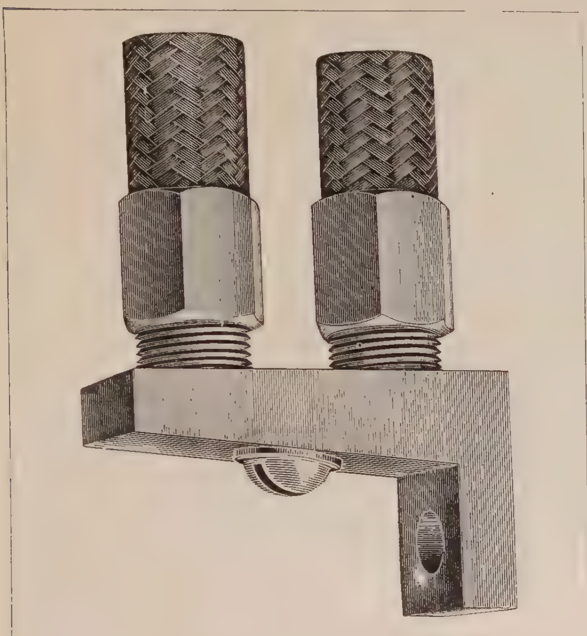
SOLDERLESS-Connectors and Terminals



The New Two-Conductor Dossert Lug

Panel Showing Two-Conductor and Single-Conductor Dossert Lugs

A New Dossert Lug

A new Dossert lug that incorporates many advantages over the present available types of lugs has been adopted and put in use by one of the big central stations. It is designed to enable the use of two wires on a terminal where the spacing does not allow them to be placed side by side.

This new lug simplifies the changing of a panel without interruption to the service. Binding screws are provided on the back of the lug to permit a short-circuiting strap to be used while the change is being made.

It has been the experience of this central station, which is replacing many panels because of the development of the system, that most of the preparatory work for these changes can be done during regular working hours by using a jumper with a straight lug on one end and a Dossert Tee connector on the other. The operation is simple. The street cable lug is lifted and the new type Dossert lug put on and reconnected to the panel. The Dossert Tee is put on the house cable and the other end on the street cable lug, thus enabling the workman to lift the house cable, replace the old style lug with the new, reconnect to the panel and then simply remove the jumper. When the panel is to be removed entirely, the short-circuiting strap gives uninterrupted service from the secondary street mains.

The accompanying illustrates the new style lug with the old on a panel.

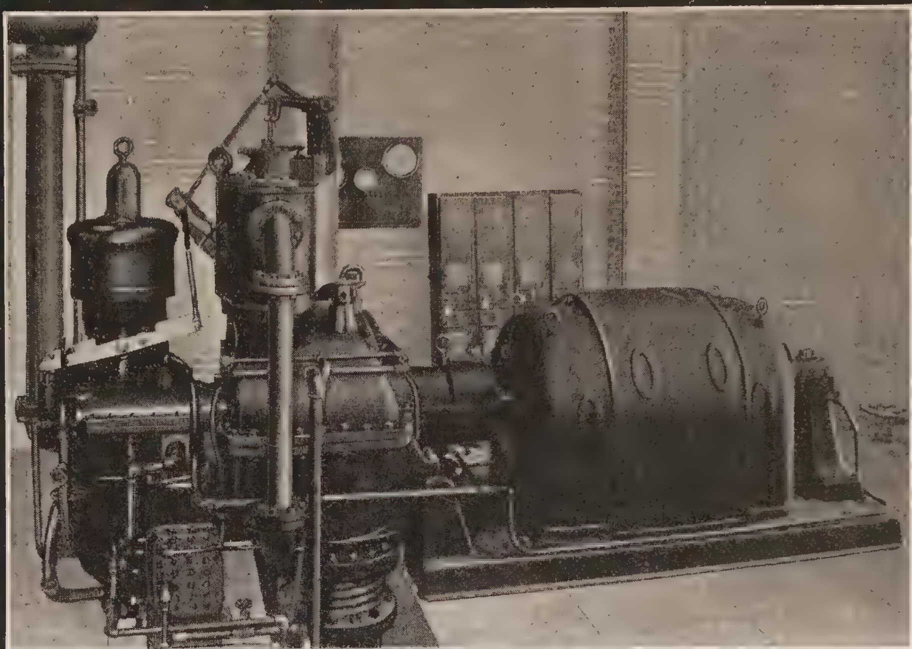
There is a type for every service—and the Dossert Catalog No. 15 gives you the data on each type.

Write for a copy.

DOSSERT & COMPANY

242 WEST 41st STREET H. B. LOGAN, PRESIDENT NEW YORK, N. Y.

Westinghouse
Turbine-Generators



WESTINGHOUSE ELECTRIC

A 500-kw. Westinghouse Turbine - Generator; 3-phase, 60-cycle, 480-volts; 130 lbs. steam pressure, 15-lbs. back pressure at exhaust. National Boxing Company, Natchez, Miss., manufacturers of wooden and cardboard boxes for packing purposes. Exhaust steam used in manufacturing processes. Excess power supplied to city and to private enterprises.

The present range of Westinghouse Turbine-Generator capacities is—

One to 70,000 Kw.

Westinghouse Steam Turbines have justly earned an international reputation for reliable and economical operation.

Westinghouse Electric & Mfg. Co.

East Pittsburgh, Pa.

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The Standard of Quality

Low depreciation rates and better service win eventually on any system. A decided advance toward maximum economy will follow if you buy "Type H Transformers." The long life characteristics of the "Type H" form a tangible asset which can be relied upon. The claim for long life is based on actual service records, not theory or probability alone.

General Electric Company

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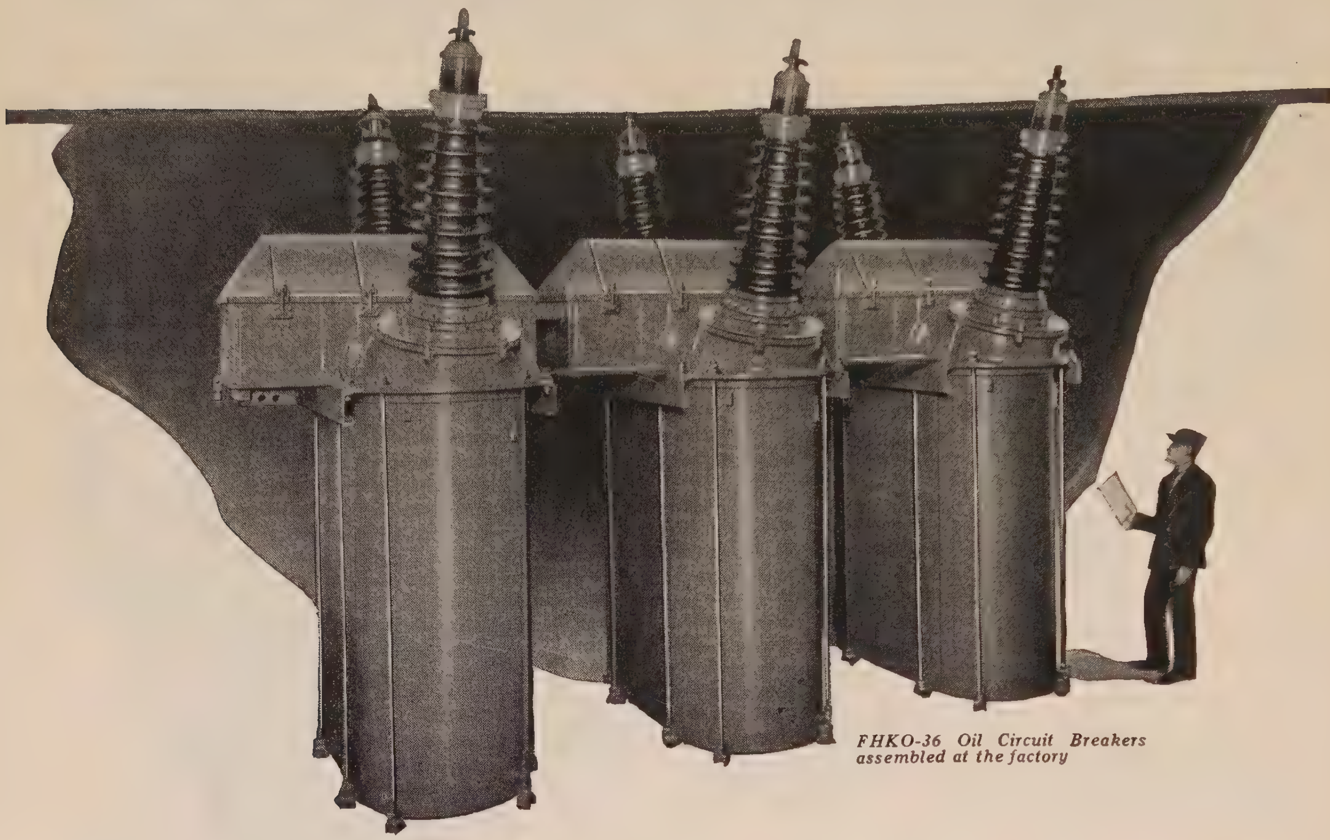
33A-97

Circuit Breakers for Pit River Project



FHKO-36 Oil Circuit Breakers assembled at the factory

At the Main Distributing Center

The Pacific Gas and Electric Company selected G-E switching equipment for its Vacaville sub-station, that important center where power is stepped down for distribution to buses which tie in with other generating plants feeding the system.

The 115,000-volt oil circuit breakers are of the FHKO-36 type with explosion chambers. These are representative of a line that is specially designed to meet the severe service conditions of large power systems. Their success is evidenced by performance in a large number of installations.

FH, Type 15,000-volt breakers are used at this sub-station in the synchronous condenser circuit, and also in Hat Creek generating stations Nos. 1 and 2 and Pit River Station No. 1. All Switchboard Panels in these stations were designed from standard G-E apparatus.

General Electric Company

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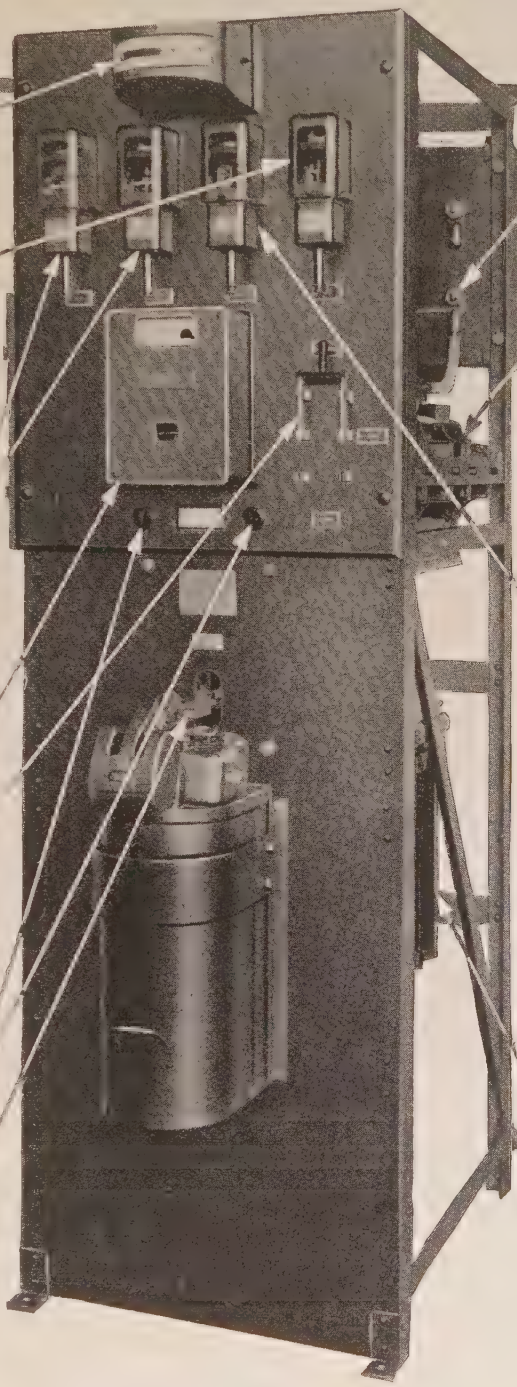
54A-59

Automatic reclosing equipment for a-c. circuits



Ammeter

Reclosing Relay
Provides definite time interval between opening and reclosing of breaker.

Overload Relays
Open oil circuit breaker on overload.

Watthour Meter

Control Power Switch
In upper position, allows breaker to reclose automatically.
In lower position, opens breaker and suspends automatic reclosing feature.

Indicating Lamps

Motor Mechanism for Operating Oil Circuit Breaker

Disconnecting Switch

Current Transformer

Notching Relay

Function:
Suspends automatic reclosing feature, if the breaker is opened three consecutive times, providing the time interval between each opening is less than a predetermined value.

Operation:
The first opening of the breaker causes the relay to notch one step on the ratchet mechanism, but the relay contacts are not opened.

The second opening of the breaker (within a predetermined time) causes the relay to notch the second step on the ratchet mechanism, but the relay contacts are not opened.

The third opening of the breaker (within the same predetermined time) causes the relay to notch the third step on the ratchet mechanism. The contacts of the relay open immediately and remain locked in this position.

If, on the first or second step of the notching relay, the breaker had remained closed, the relay would have returned to its original position. Subsequent openings of the breaker would then start a fresh sequence of operations of the relay and breaker.

Oil Circuit Breaker

Self-supporting Framework

Shipped completely wired and assembled

Refer to Bulletin 47716-A for further information or ask our specialist in the nearest G-E Sales Office.

General Electric Company

General Office Schenectady, N.Y.

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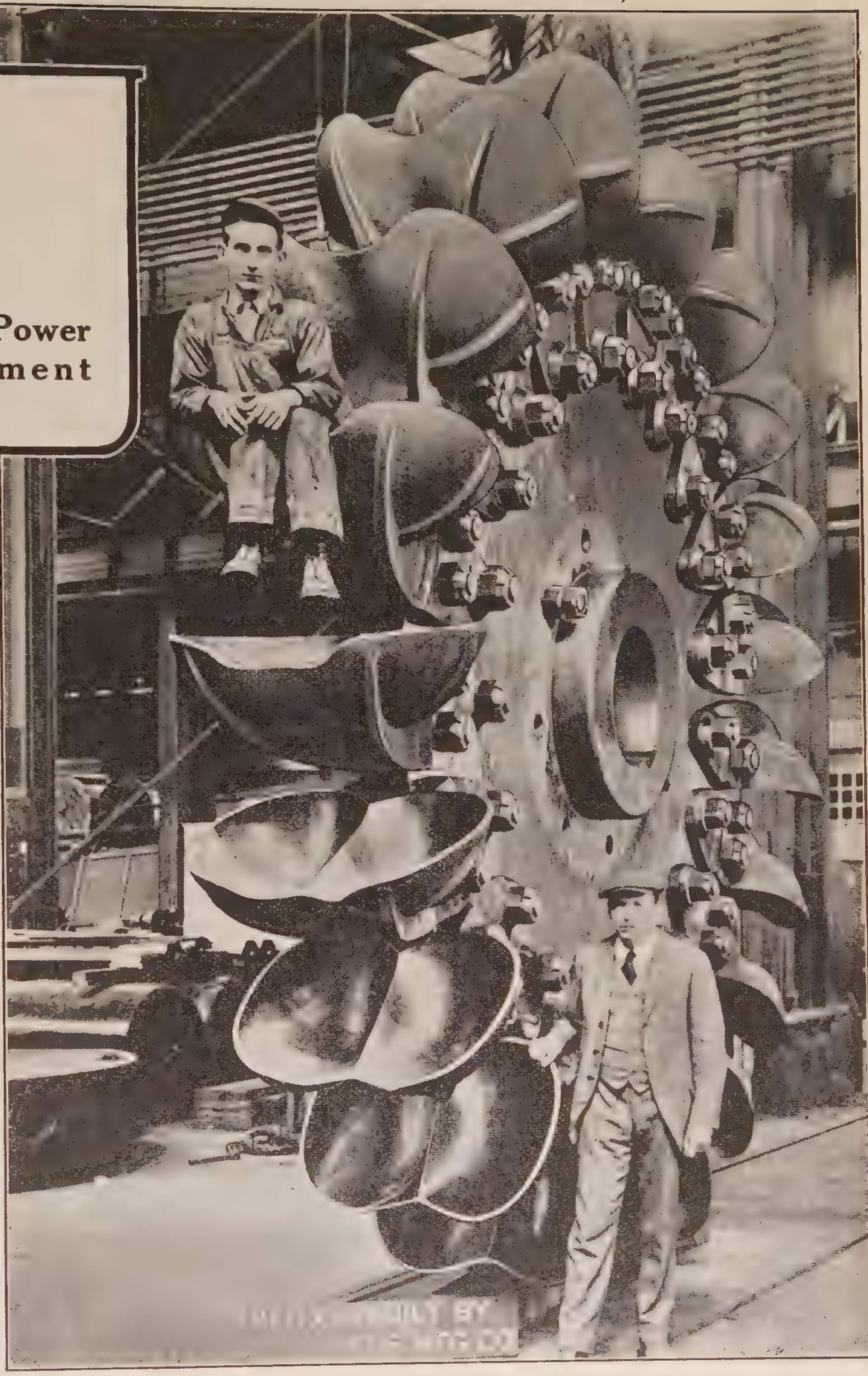
54C-73

A New Record

In Water Power Development



Monster impulse wheel for Caribou Plant, Great Western Power Company.
Weight 25 Tons.

PRINCIPAL DESIGN FEATURES

Double Overhung Impulse Type Water Wheels for Great Western Power Company, Caribou Plant, Belden, California. Largest machines of this type ever built, both in physical dimensions as well as capacity.

Two units furnished, each developing 30,000 H. P. under 1008 ft. effective head, 171 R. P. M. Each unit has two impulse wheel discs like the one illustrated, which are mounted on opposite ends of the main turbine and generator shaft.

Unique needle control consisting of regulating cylinder with piston operated by oil pressure from central oil system and directly connected to extension of needle stem.

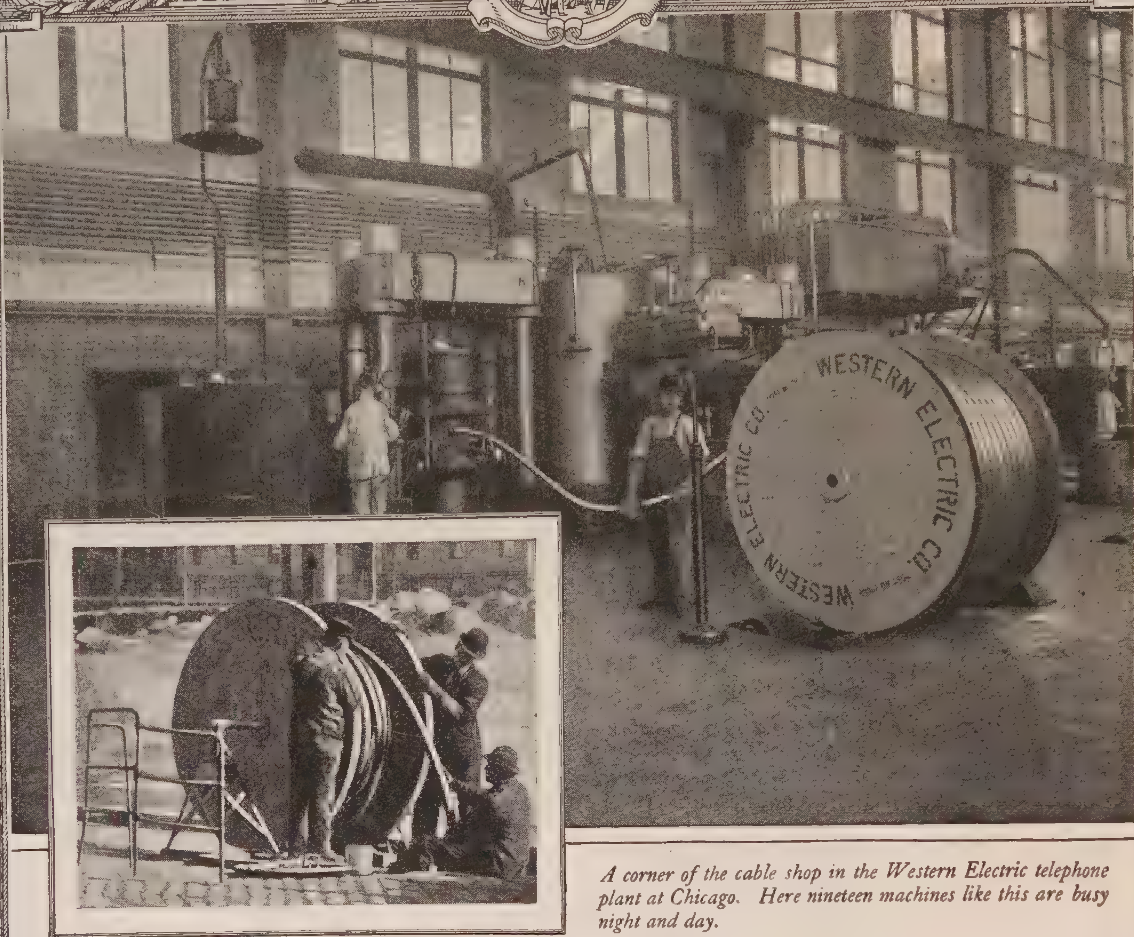
Automatic pressure regulators and separate governor control for each needle nozzle. Governor control arranged for operating one-half of unit independent of the other, thus giving increased flexibility in operation.

Main turbine shaft 30 feet long. Maximum diameter 30 inches. Inspection Hole 8 in. diameter hollow bore. Main shaft carried in two self-aligning ring oiling bearings with babbitted shells 24¾ in. diameter by 72 in. long.

Our Engineering Department which produced these original design features is at your service in all Hydro-Electric Problems

ALLIS-CHALMERS

MILWAUKEE, WIS. U. S. A.



A corner of the cable shop in the Western Electric telephone plant at Chicago. Here nineteen machines like this are busy night and day.

A familiar scene, and what's behind it

To you who have wondered how telephone cable is made, a simple answer would be "One machine winds the wires and another puts a lead covering around them."

But that gives small idea of the task in producing 6000 miles of cable each year from more than two million miles of copper wire, each wire separately insulated and all compressed into a diameter of an inch or two and sealed with a covering of molten lead.

Western Electric is the largest manufacturer of telephone cable in the world.

Yet all this is only one phase of the Western Electric Company's work of making telephones and telephone equipment—and making them in great quantities, yet with extraordinary accuracy.

Western Electric

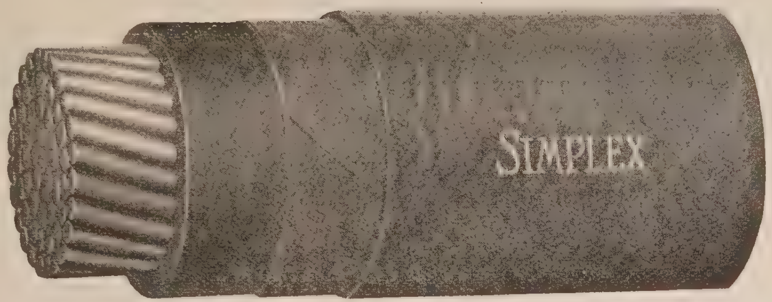
Since 1869 Makers of Electrical Equipment

Rubber Covered Wires and Cables

National Electrical Code Standard

FOR FACTORIES AND OFFICE BUILDINGS

FOR SCHOOLS AND PUBLIC BUILDINGS



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Engineers: Thomas E. Murray, Inc.

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The recognized high quality of STANDARD Products is the result of over 40 years of specialized research and continuous improvement in the art of wire and cable manufacture. This experience is at the service of our customers.

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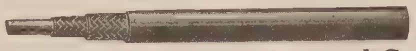
"AMERICAN BRAND"



Weatherproof Copper Wire and Cables

COST

You can buy weatherproof wire cheap, but is it worth what it costs.

"AMERICAN BRAND" gives you more mileage per dollars with a longer life on the line.

Get a sample and satisfy yourself.

American Insulated Wire & Cable Co.
954 West 21st Street, Chicago

DOLPHIN ATLANTIC

ATLANTIC
INSULATED WIRES

DOLPHIN Insulated Wire

A code wire of high quality known for its great dielectric strength and resiliency, and used for its dependability and maximum service. Built on the same lines as the widely known and used "Neptune"—30% para; and "Triton"—High grade.

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have for over twelve years been standard among electrical manufacturers due to their dependable quality and reasonable price. Find out the economy and improvement we can effect for you.

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Fort Wayne, Ind.

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For Varied Applications

We manufacture many types of wires, cords and cables for specific uses. Among them are:

Rubber Covered Wire—Solid Conductor, Stranded Conductor, Flexible Conductor, Extra Flexible Conductor.

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When designing that large Transformer or Generator bear in mind that we are now furnishing

Square and Rectangular Conductors

in the same eternally good

Beldenamel
TRADE MARK

insulation that has stood between you and so much trouble with windings made of round wire.

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Morganite Brush Co., Inc.
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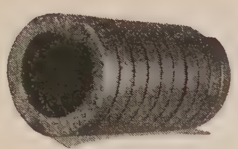
Composition
American Insulator Corp., New Freedom, Pa.
Bakelite Corporation, New York.
Belden Mfg. Co., Chicago
Condensite Co. of America, Bloomfield, N.J.
Cutler-Hammer Mfg. Co., Milwaukee.
General Bakelite Co., New York.
Redmanol Chemical Products Co., Chicago
Waterbury Button Co., Waterbury, Conn.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

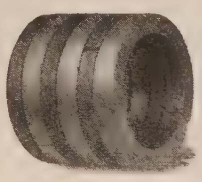
A COMPLETE SERVICE IN

"John Crane"

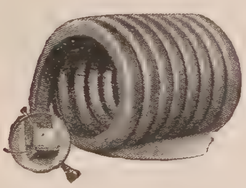
FLEXIBLE METALLIC PACKING



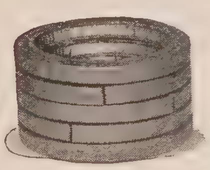
Style 100—Babbitt foil impregnated with purest graphite. Wrapped spirally. For rods in line. Flexible. Uniform. Compressible.



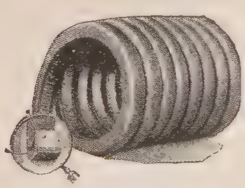
Style 104—Slow speed ammonia sets.



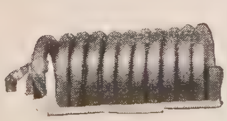
Style 400—Resilient duck channel with flexible metallic wearing face.



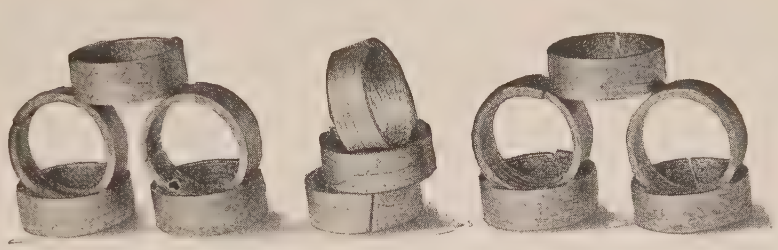
Style 401—Cut rings from Style 400.



Style 300—Resilient asbestos channel.



Style 200—Copper foil.



Style 601—Renders condensers absolutely leak proof and saves tubes from destructive stress and corrosion.

Condenser Tube Packing

Now Approved in Highest Engineering Circles

This "John Crane" process is fully protected by U. S. patent No. 1,387,901, August 16, 1921. It is also fully protected by foreign patents.

Attention of engineers the nation over has recently been directed to the "John Crane" Process of Condenser Tube Packing.

In marine service (and there is none harder) our metallic packing is standing up better than anything else ever devised. Many condensers built by Westinghouse, Wheeler, Worthington, Alberger and Elliott are now packed with "John Crane."

When we put three times ordinary pressure on a demonstration condenser especially heavy shell packed with "John Crane" Condenser Tube Packing and without ferrules, and rapidly alternate hot and cold water no leaks develop. This demonstration outfit we plan to send to various points in the United States. If you would like to see it operate, write us and we will see that you are notified.

The Story Complete

In the meantime, investigate this process. Send your name for our complete text book on the subject.

Crane Packing Company

1804 Cuyler Ave., CHICAGO

NEW YORK:	PHILADELPHIA:	HOUSTON:
706 Dodge Bldg.	101 Walnut Street	617 Washington Ave.

CANADA: Flexible Metallic Packing Co., Ltd., Windsor, Ont.

Classified Advertiser's Index for Buyers—*Continued.*

INSULATING MATERIALS—*Continued.*

Compounds
Minerallac Electric Co., Chicago
Western Electric Co., All Principal Cities.

Fibre
Diamond State Fibre Co., Bridgeport, Pa.
National Fibre & Ins. Co., Wilmington, Del.

Lava
American Lava Co., Chattanooga, Tenn.

Paper
Irvington Varnish & Ins. Co., Irvington, N. J.

Silk
Irvington Varnish & Ins. Co., Irvington, N. J.

Slate
Structural Slate Co., The, Pen Argyl, Pa.

Tape
Belden Mfg. Co., Chicago
Minerallac Electric Co., Chicago
Okonite Co., The. New York
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Varnishes
General Electric Co., Schenectady, N. Y.
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago

INSULATORS, HIGH TENSION.

Composition
General Electric Co., Schenectady, N. Y.

Glass
Hemingray Glass Co., Muncie, Ind.

Porcelain
General Electric Co., Schenectady, N. Y.
Jeffrey-Dewitt Insulator Co., Kenova. W. Va
Locke Insulator Mfg. Co., Victor, N. Y.
Ohio Brass Co., Mansfield, O.
Thomas & Sons Co., R., East Liverpool, O.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

INSULATORS, TELEPHONE & TELEGRAPH
Hemingray Glass Co., Muncie, Ind.
Western Electric Co., All Principal Cities.

LAMP GUARDS.
Western Electric Co., All Principal Cities.

LAVA.
American Lava Co., Chattanooga, Tenn.

LIGHTNING ARRESTERS.
Electro Service Co., Marietta, Ga.
General Electric Co., Schenectady, N. Y.
Railway & Industrial Engg. Co., Greensburg, Pa.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

LOCOMOTIVES, ELECTRIC.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

LUBRICANTS.
Texas Oil Co., New York

MAGNET WIRE.
Acme Wire Co., New Haven, Conn.
Belden Mfg. Co., Chicago
Dudlo Mfg. Co., Ft. Wayne, Ind.
Roebling's Sons Co., J. A., Trenton, N. J.
Western Electric Co., All Principal Cities

METALLIC PACKING.
Crane Packing Co., Chicago

METERS, ELECTRICAL.
(See INSTRUMENTS, ELECTRICAL.)

METER LOADING DEVICES.
States Co., The, Hartford, Conn.

MOLDED INSULATION.
American Insulator Corp., New Freedom, Pa.
Bakelite Corporation, New York.
Belden Mfg. Co., Chicago
Condensite Co. of America, Bloomfield, N. J.
Cutler-Hammer Mfg. Co., Milwaukee.
General Bakelite Co., New York.
Redmanol Chemical Products Co., Chicago
Waterbury Button Co., Waterbury, Conn.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

MOTORS.
(See GENERATORS AND MOTORS.)

PANEL BOARDS.
(See SWITCHBOARDS.)

PATENT ATTORNEYS.
(See PROFESSIONAL ENGINEERING DIRECTORY.)

PHASE MODIFYING APPARATUS.
States Co., The, Hartford, Conn.

PHOTOMETERS—SPHERES.
Foote, Pierson & Co., Inc., New York

PHOTOSTATS.
Photostat Corp., Rochester, N. Y.

PLUGS.
Cutler-Hammer Mfg. Co., Milwaukee.
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

POLES, STEEL.
Bates Expanded Steel Truss Co., Chicago
Western Electric Co., All Principal Cities.

POLES—TIES, WOOD.
Naugle Pole & Tie Co., Chicago
Page & Hill Co., Minneapolis, Minn.
Partridge Lumber Co., T. M., Minneapolis
Valentine-Clark Co., Minneapolis, Minn.
Western Electric Co., All Principal Cities.

POTHEADS.
G & W Electric Specialty Co., Chicago
Thoner & Martens, Boston
Western Electric Co., All Principal Cities.

PROTECTIVE DEVICES.
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities.

PULLEYS, PAPER.
Rockwood Mfg. Co., The, Indianapolis

PUMPS.
Allis-Chalmers Mfg. Co., Milwaukee
Goulds Mfg. Co., Seneca Falls, N. Y.

PYROMETERS.
Leeds & Northrup Co., Philadelphia

RADIO INSULATING PARTS.
Waterbury Button Co., Waterbury, Conn.

RADIO LABORATORY APPARATUS.
Acme Apparatus Co., Cambridge, Mass.
General Radio Co., Cambridge, Mass.
Waterbury Button Co., Waterbury, Conn.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RAILWAY SUPPLIES, ELECTRIC
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, O.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

REACTANCE COILS.
Metropolitan Device Corp., Brooklyn, N. Y.

RECTIFIERS.
General Electric Co., Schenectady, N. Y.
Wagner Electric Mfg. Co., St. Louis.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

REGULATORS, VOLTAGE.
General Electric Co., Schenectady, N. Y.
States Co., The. Hartford. Conn.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RESISTANCE ELEMENTS.
Cutler-Hammer Mfg. Co., Milwaukee.
General Electric Co., Schenectady, N. Y.
Wiegand Company, Edwin L., Pittsburgh

RHEOSTATS.
Cutler-Hammer Mfg. Co., Milwaukee.
Biddle, James G., Philadelphia, Pa.
General Electric Co., Schenectady, N. Y.
Waterbury Button Co., Waterbury, Conn.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

ROPE, WIRE.
Roebling's Sons Co., John A., Trenton, N. J.

SEARCHLIGHTS.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SLATE.
Structural Slate Co., The, Pen Argyl, Pa.

SOCKETS AND RECEPTACLES.
Cutler-Hammer Mfg. Co., Milwaukee.
General Electric Co., Schenectady, N. Y.
Waterbury Button Co., Waterbury, Conn.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SOLENOIDS.
Acme Wire Co., New Haven, Conn.
Belden Mfg. Co., Chicago
Cutler-Hammer Mfg. Co., Milwaukee.
Dudlo Mfg. Co., Ft. Wayne, Ind.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

STOKERS, MECHANICAL.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SUB-STATIONS.
Electro Service Co., Marietta, Ga.
General Electric Co., Schenectady, N. Y.
Railway & Industrial Eng'g. Co., Greensburg, Pa.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SWITCHBOARDS.
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Condit Electrical Mfg. Co., So. Boston, Mass.
General Electric Co., Schenectady, N. Y.
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SWITCHES.

Automatic Time
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Disconnecting
Condit Elec. & Mfg. Co., So. Boston.
General Electric Co., Schenectady, N. Y.
K-P-F Elec. Co., San Francisco
Railway & Ind. Eng'g. Co., Greensburg, Pa.
Thoner & Martens, Boston

Fuse
General Electric Co., Schenectady, N. Y.
Metropolitan Device Corp., Brooklyn, N. Y.
Thoner & Martens, Boston

Knife
Condit Elec. & Mfg. Co., So. Boston, Mass.
Cutter Company, The, Philadelphia.
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Oil
Condit Elec. & Mfg. Co., So. Boston, Mass.
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Remote Control
Condit Elec. & Mfg. Co.. So. Boston
Cutler-Hammer Mfg. Co., Milwaukee.
General Electric Co., Schenectady, N. Y.
Railway & Ind. Eng. Co., Greensburg, Pa.
Rowan Controller Co., Baltimore
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co. E. Pittsburgh

TACHOMETERS.
Biddle, James G., Philadelphia

TELEGRAPH APPARATUS.
Foote, Pierson & Co., Inc., New York
Western Electric Co., All Principal Cities.

TELEPHONE EQUIPMENT.
Western Electric Co., All Principal Cities

TESTING LABORATORIES.
Electrical Testing Labs., New York

TOWERS, TRANSMISSION.
Bates Expanded Steel Truss Co., Chicago
Western Electric Co., All Principal Cities.

TRANSFORMERS.
Acme Apparatus Co., Cambridge, Mass.
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
American Transformer Co., Newark, N. J.
Duncan Elec. Mfg. Co., Lafayette, Ind.
Ferranti, Ltd., London, Eng.
General Electric Co., Schenectady, N. Y.
Kuhlman Electric Co., Bay City, Mich.
Moloney Elec. Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh
Wagner Elec. Corp., St. Louis.
Western Electric Co., All Principal Cities.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Factory
American Transformer Co., Newark, N. J.
Kuhlman Electric Co., Bay City, Mich.
Moloney Elec. Co., St. Louis, Mo.
Pittsburgh Transformer Co., Pittsburgh
Wagner Elec. Corp., St. Louis.
Western Electric Co., All Principal Cities.

Furnace
Allis-Chalmers Mfg. Co., Milwaukee
American Transformer Co., Newark, N. J.
Moloney Elec. Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh

Metering
American Transformer Co., Newark, N. J.
Pittsburgh Transformer Co., Pittsburgh, Pa.

Mill Type
Pittsburgh Transformer Co., Pittsburgh

Street Lighting
Kuhlman Electric Co., Bay City, Mich.
Western Electric Co., All Principal Cities.

Classified Advertiser's Index for Buyers—*Continued.*

TROLLEY LINE MATERIALS.
- Ohio Brass Co., Mansfield, O.
- Western Electric Co., All Principal Cities.
- Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TURBINES, HYDRAULIC.
- Allis-Chalmers Mfg. Co., Milwaukee

TURBINES, STEAM.
- Allis-Chalmers Mfg. Co., Milwaukee, Wis.
- General Electric Co., Schenectady, N. Y.
- Western Electric Co., All Principal Cities
- Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TURBO-GENERATORS.
- Allis-Chalmers Mfg. Co., Milwaukee, Wis.
- Westinghouse Elec. & Mfg. Co., E. Pittsburgh

VARNISHES, INSULATING.
- General Electric Co., Schenectady, N. Y.
- Irvington Varnish & Ins. Co., Irvington, N. J.
- Mineralac Electric Co., Chicago
- Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

WELDING EQUIPMENT, ELECTRICAL
- General Electric Co., Schenectady, N. Y.
- Ohio Brass Co., Mansfield, O.
- Westinghouse Elec. & Mfg. Co., E. Pittsburgh

WIRELESS APPARATUS.
- Acme Apparatus Co., Cambridge, Mass.
- General Radio Co.. Cambridge. Mass
- Waterbury Button Co., Waterbury, Conn.
- Westinghouse Elec. & Mfg. Co., E. Pittsburgh

WIRES AND CABLES.

Armored Cable
- Belden Mfg. Co., Chicago
- Boston Ins. Wire & Cable Co., Boston
- General Electric Co., Schenectady, N. Y.
- Kerite Ins. Wire & Cable Co., New York
- Okonite Company, The, Passaic, N. J.
- Roebling's Sons Co., John A., Trenton, N. J.
- Standard Underground Cable Co., Pittsburgh
- Western Electric Co., All Principal Cities

Auto
- Belden Mfg. Co., Chicago
- Boston Ins. Wire & Cable Co., Boston
- General Electric Co., Schenectady, N. Y.
- Kerite Ins. Wire & Cable Co., New York
- Roebling's Sons Co., John A., Trenton, N. J.
- Standard Underground Cable Co., Pittsburgh
- Western Electric Co., All Principal Cities

Bare Copper
- American Copper Products Corp., New York
- American Ins. Wire & Cable Co., Chicago
- Anaconda Copper Mining Co., Chicago
- Belden Mfg. Co., Chicago
- Copper Clad Steel Co., Rankin, Pa.
- Roebling's Sons Co., John A., Trenton, N. J.
- Standard Underground Cable Co., Pittsburgh
- Western Electric Co., All Principal Cities

Copper Clad
- American Copper Products Corp., New York
- Copper Clad Steel Co., Rankin, Pa.
- Standard Underground Cable Co., Pittsburgh
- Western Electric Co., All Principal Cities

Flexible Cord
- Belden Mfg. Co., Chicago
- Boston Ins. Wire & Cable Co., Boston
- General Electric Co., Schenectady. N. Y.
- Okonite Company, The, Passaic, N. J.
- Roebling's Sons Co., John A., Trenton, N. J.
- Standard Underground Cable Co., Pittsburgh
- Western Electric Co., All Principal Cities

Fuse
- General Electric Co., Schenectady, N. Y.
- Roebling's Sons Co., John A., Trenton, N. J.
- Western Electric Co., All Principal Cities

Lead Covered (paper and varnished cambric insulated)
- Atlantic Ins. Wire & Cable Co., New York
- General Electric Co., Schenectady, N. Y.
- Kerite Ins. Wire & Cable Co., New York
- Okonite Company, The, Passaic, N. J.
- Roebling's Sons Co., John A., Trenton, N. J.
- Simplex Wire & Cable Co., Boston
- Standard Underground Cable Co., Pittsburgh
- Western Electric Co., All Principal Cities

Magnet
- Acme Wire Co., New Haven, Conn.
- Belden Mfg. Co., Chicago
- Dudlo Mfg. Co., Fort Wayne, Ind.
- General Electric Co., Schenectady, N. Y.
- Roebling's Sons Co., John A., Trenton, N. J.
- Standard Underground Cable Co., Pittsburgh
- Western Electric Co., All Principal Cities

Rubber Insulated
- Atlantic Ins. Wire & Cable Co., New York
- Belden Mfg. Co., Chicago
- Boston Ins. Wire & Cable Co., Boston
- General Electric Co., Schenectady, N. Y.
- Kerite Ins. Wire & Cable Co., New York
- Okonite Company, The, Passaic, N. J.
- Roebling's Sons Co., John A., Trenton, N. J.
- Simplex Wire & Cable Co., Boston
- Standard Underground Cable Co., Pittsburgh
- Western Electric Co., All Principal Cities

Trolley
- American Copper Products Corp., New York
- Anaconda Copper Mining Co., Chicago
- Copper Clad Steel Co., Rankin, Pa.
- Roebling's Sons Co., John A., Trenton, N. J.
- Standard Underground Cable Co., Pittsburgh
- Western Electric Co., All Principal Cities

Weatherproof
- American Copper Products Corp., New York
- American Ins. Wire & Cable Co., Chicago
- Copper Clad Steel Co., Rankin, Pa.
- General Electric Co., Schenectady, N. Y.
- Kerite Ins. Wire & Cable Co., New York
- Okonite Company, the, Passaic, N. J.
- Roebling's Sons Co., John A., Trenton, N. J.
- Simplex Wire & Cable Co., Boston, Mass.
- Standard Underground Cable Co., Pittsburgh
- Western Electric Co., All Principal Cities

ALPHABETICAL LIST OF ADVERTISERS

(For classified list of Advertisers see Pages 36, 38 and 40)

Please mention the JOURNAL of the A. I. E. E. when writing to advertisers.

Metropolitan Reactors

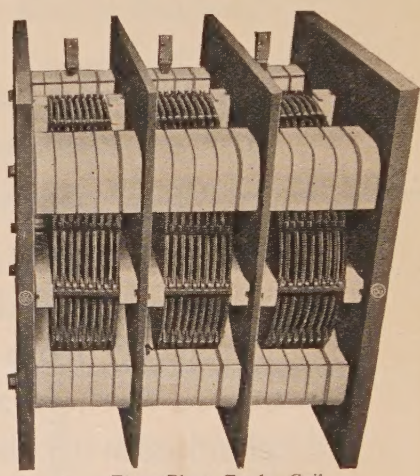
have just been ordered by the

EDISON ELECTRIC ILLUMINATING CO.
BOSTON, MASS.

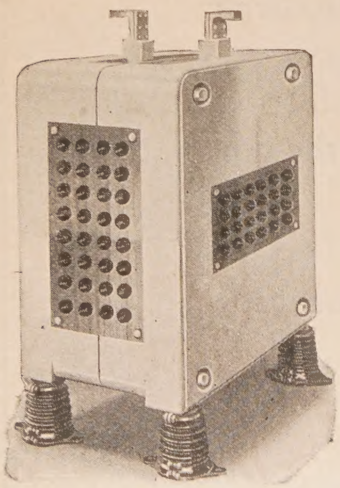
When a central station manager is in doubt as to the kind of current-limiting reactors to install—it is a good idea to check up what equipment is used by the greatest and most economical generating plants in this country.

Metropolitan Reactors, for instance, are used by the big Edison Companies in New York, Chicago, Detroit, Brooklyn, etc. Also they are standard equipment not only in the central station, but in the industrial field as well.

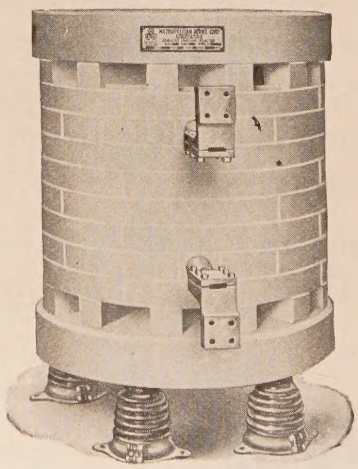
Short circuits cannot be prevented as yet, but you can do the next best thing, install Metropolitan Reactors and protect your equipment from abnormal and dangerous stresses. Just clip the coupon.



Three-Phase Feeder Coil



Indoor service 25 to 350 Amp.



Indoor service 350 to 750 Amp.

Partial List of Installations of Metropolitan Reactors

Edison Elec. Illuminating Co., Boston, Mass.
Brooklyn Rapid Transit Co., Brooklyn, N. Y.
Calgary Municipal Electric Co., Calgary, Canada
Canadian Niagara Falls Power Co., Niagara Falls, Ont.
Cataluna Power Co., Barcelona, Spain
Chicago, Lake Shore & So. Bend R. R., Mich. City, Ind.
Cohoes Light & Power Corp., Cohoes, N. Y.
Commonwealth Edison Co., Chicago, Ill.
Consolidated Gas & Electric Co., Baltimore, Md.
Dayton Power & Light Co., Dayton, Ohio
East Hampton Gas Co., East Hampton, Mass.
Edison Electric Illuminating Co., Brooklyn, N. Y.
Edison Illuminating Co., Detroit, Mich.
El Paso Power & Railroad Co., El Paso, Texas
French General Electric Co., Paris, France
Hydro Electric Power Commission, Toronto, Ontario
Interborough Rapid Transit Co., New York, N. Y.
Joyce Gridland Railroad Co., London, England
Municipal Gas & Electric Co., Albany, N. Y.
New York Edison Company, New York, N. Y.
N. Y., N. H. & H. R. R. Co., West Farms, N. Y.
N. Y. & Queens Elec. Lt. & Pwr. Co., L. I. City, N. Y.
Potomac Electric Co., Washington, D. C.
Public Works Department, Lake Cooleridge, N. Z.
Public Service Electric Co., Newark, N. J.
Shawinigan Hydro El. Pwr. Co., Shawinigan Falls, Ont.
Tennesee Power Co., Chattanooga, Tenn.
Toledo R. R. & Light Co., Toledo, Ohio
Toronto Power Co., Niagara Falls, Ont.
Turners Falls Power Co., Turner Falls, Mass.
United Electric Lt. & Pwr. Co., Springfield, Mass.
United Electric Lt. & Pwr. Co., New York, N. Y.
Union Gas & Electric Co., Cincinnati, Ohio
U. S. Explosives Plant, Nitro, West Va.
Utica Gas & Electric Co., Utica, N. Y.
Victoria Falls & Tranvall P. Co., Simmerpan, S. Africa
Warren & Co., Boston, Mass.
Youngstown Sheet & Tube Co., Youngstown, Ohio

CLIP THIS COUPON

Metropolitan Device Corporation
1250 Atlantic Avenue, Brooklyn, N. Y.

Gentlemen:—Please send data and full information on current limiting reactors.

Name .... Company ....

Address .... Title ....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Okonite Signal Wires
Installed throughout
THE OKONITE COMPANY
501 FIFTH AVENUE, NEW YORK
CENTRAL ELECTRIC COMPANY
General Western Agents
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F. D. Lawrence Electric Co.
Cincinnati, O.
Novelty Electric Co.
Philadelphia, Pa.
Pettingell-Andrews Co.
Boston, Mass

American Institute of Electrical Engineers

COMING MEETINGS

Midwinter Convention, New York, February 14-16

Spring Convention, Pittsburgh, April

Annual Convention, Swampscott, Mass., June, 25-29

Pacific Coast Convention, San Francisco, September

MEETINGS OF OTHER SOCIETIES

American Chemical Society, New York, December, 8

American Institute of Chemical Engineers, Richmond, Va., December, 6-9

American Institute of Mining and Metallurgical Engineers, Annual Meeting, New York, February, 19-21

American Physical Society, Boston, December. 26-30

American Society of Civil Engineers, New York, January, 17-18

American Society of Mechanical Engineers, New York, December, 4-7

American Society of Refrigerating Engineers, New York, December, 5-7

Society of Automotive Engineers, Annual Meeting, New York, January, 9-12